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HURRICANE HAVENS HANDBOOK FOR THE NORTH ATLANTIC OCEAN.(U)
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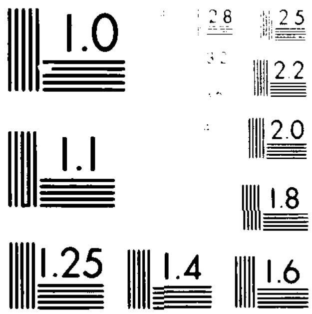

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DEPARTMENT OF THE NAVY

UNITED STATES ATLANTIC FLEET
HEADQUARTERS OF THE COMMANDER IN CHIEF
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3100/FF1-
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13 April 1

From: Commander in Chief U.S. Atlantic Fleet
To: Distribution List

Subj: Hurricane Havens Handbook

Encl: (1) Hurricane Havens Handbook for the North Atlantic (

1. Enclosure (1) was developed by the Naval Environmental Prediction Research Facility Monterey, California to evaluate selected deep water ports as hurricane havens for ships of tl Atlantic Fleet. Changes to this handbook will be issued as additional haven studies become available.

2. Tropical cyclones can be a formidable and dangerous foe, sea and in port. Storm damage can degrade our ability to fic may result in expensive repairs, not to mention the potential personnel casualties. Prudent, early action by commanders ar commanding officers in response to tropical warnings is esser Deviation from standard and recommended hurricane evasion tac can be justified only by extreme operational necessity. Flee capabilities must not be degraded due to casualties resulting tropical storms and hurricanes.

3. Enclosure (1) is intended to aid commanders and commandir officers in evaluating hurricane situations and to assist the making decisions whether to sortie to evade, or remain in poi take shelter within a harbor. Comments concerning the useful this handbook are encouraged.

K. E. Moranville
K. E. MORANVILLE
Deputy Chief of S

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NAVENVPREDRSCHFAC Technical Report TR 82-03	2. GOVT ACCESSION NO. AD-A116401	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Hurricane Havens Handbook for the North Atlantic Ocean		5. TYPE OF REPORT & PERIOD COVERED Final
		6. PERFORMING ORG. REPORT NUMBER TR 82-03
7. AUTHOR(s) LCDR Roger J.B. Turpin and Samson Brand		8. CONTRACT OR GRANT NUMBER(s) N00228-80-C-Y402 N00228-81-C-K123
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Environmental Prediction Research Facility Monterey, CA 93940		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS NEPRF WU OMN-1
11. CONTROLLING OFFICE NAME AND ADDRESS Commander, Naval Oceanography Command NSTL Station Bay St. Louis, MS 39529		12. REPORT DATE June 1982
		13. NUMBER OF PAGES 282
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

(1) Advance copies of Sections II,III,IV,V,VII were distributed to U.S. Atlantic Fleet between 20 May and 8 September 1981.
(2) Qualified requestors may obtain additional copies from Defense Technical Information Center; others apply to National Technical Information Service.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Hurricane
Tropical cyclone
Hurricane haven
Tropical meteorology
Warnings
Forecasts
Strike probability

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This Handbook is a ready-reference decision-making aid for commanding officers or other individuals responsible for the safety of ships facing a hurricane threat. Guidance on assessing a hurricane threat and choosing appropriate countermeasures at specific North Atlantic ports is provided in Sections II-onward. However, the Handbook is not exclusively dedicated to ships at these ports, and the general guidance of Section I will assist ships at other ports or at sea.

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CONTENTS

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FOREWORD

Following the publication by the Naval Environmental Prediction Research Facility (NEPRF) in 1976 of the Typhoon Havens Handbook for the Western Pacific and Indian Oceans, the Commander SECOND Fleet and the Commander-in-Chief U.S. Atlantic Fleet stated a requirement for certain ports of the North Atlantic - including the Gulf of Mexico and Caribbean Sea - to be similarly evaluated as hurricane havens.

The aim of the Hurricane Havens Handbook for the North Atlantic Ocean is to provide a ready-reference, decision-making aid to commanding officers or other individuals who are responsible for the safety of ships faced with a hurricane threat. It provides guidelines for making decisions in regard to evasion or remaining in port or, for ships already at sea, the seeking of shelter in port.

The development of this Handbook is a long-term and continuing project; evaluations of other ports will be published for future inclusion in the Handbook. Every effort has been made to cover most contingencies to be expected under threatened or actual hurricane conditions in the ports presented. However, the ultimate test of its value will be conducted by decision makers at threatened ports in the future. Users are therefore urged to offer comments and criticisms on the Handbook's practical utility as soon as any shortcomings become evident.

WILLIAM G. SCHRAMM
Captain, U.S. Navy
Commanding Officer

ACKNOWLEDGMENTS

The undertaking of a large study such as this one requires assistance and cooperation at many levels. The authors would like to thank the numerous Naval Oceanography Command activities, local port and harbor officials, U.S. Army, Navy, Coast Guard and National Oceanic and Atmospheric Administration personnel for contributing significant time and effort and for providing data, reports and constructive comments. All the above contributors are gratefully acknowledged as is the assistance of CDR F. K. Martin and CAPT C. M. Zucker of the CINCLANTFLT Staff. CAPT W. G. Schramm, Commanding Officer of the Naval Environmental Prediction Research Facility (NEPRF), initiated the Hurricane Havens Project and provided support, encouragement and the opportunity to undertake such an effort which he felt was needed by the Fleet. The authors also wish to thank Mr. Stephen Bishop for his editorial services and Ms. Winona Carlisle for her manuscript typing.

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Royal Navy Exchange Officer

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Tactical Applications Department

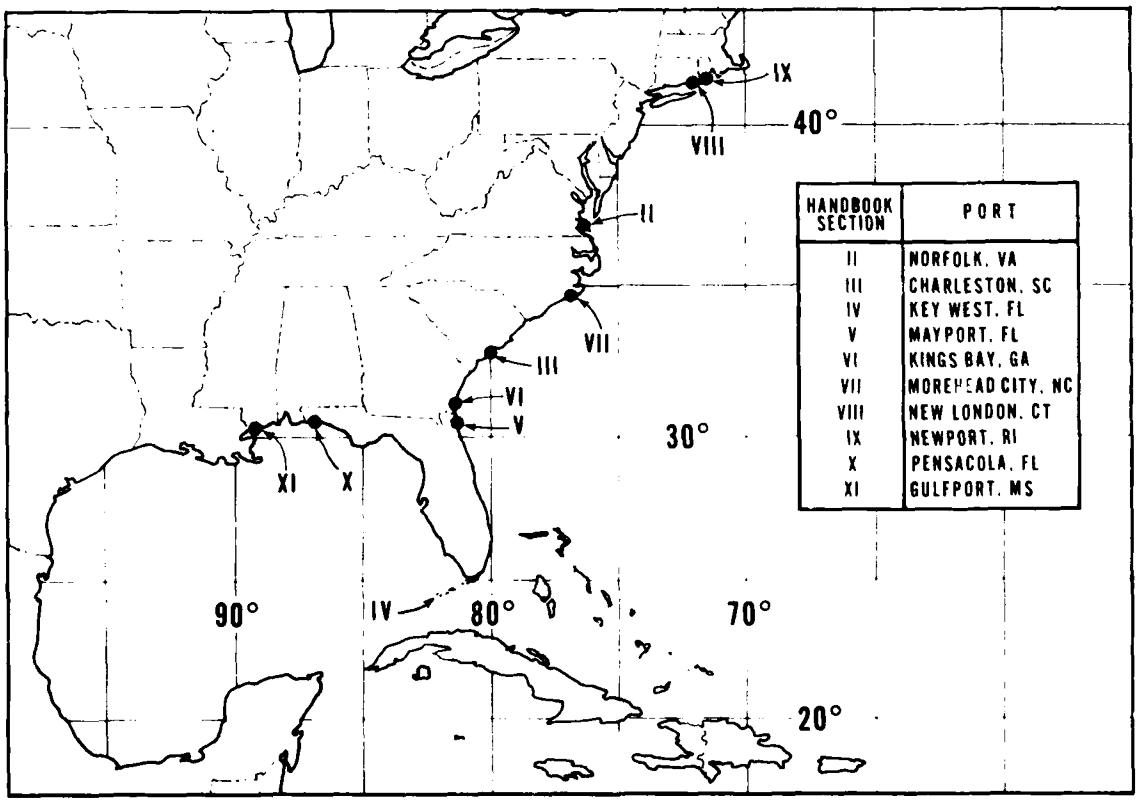
INTRODUCTION

CAUTION: None of the deep water harbors evaluated in Sections II-XI possess the exceptional qualities needed to safeguard ocean-going vessels from damage in a "worst case" direct hurricane strike.

The impact of a hurricane strike at a particular port varies widely and can, to some degree, be forecast according to the particular circumstances of the threat.

This Handbook provides guidance on assessing a particular hurricane threat in such a way that the mariner can choose between remaining in port, or putting to sea, on the basis of a reasoned compromise between overconfidence in a harbor's protective qualities and wasteful, unnecessary sorties.

The Handbook is not exclusively dedicated to ships located at those ports evaluated as hurricane havens in Sections II-onward. The general guidance of Section I will alsc assist ships threatened by hurricanes at other ports or at sea. Locations of evaluated ports are shown below.



HANDBOOK SECTION	PORT
II	NORFOLK, VA
III	CHARLESTON, SC
IV	KEY WEST, FL
V	MAYPORT, FL
VI	KINGS BAY, GA
VII	MOREHEAD CITY, NC
VIII	NEW LONDON, CT
IX	NEWPORT, RI
X	PENSACOLA, FL
XI	GULFPORT, MS

Ports evaluated in the ten Handbook sections II-XI.

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I: CONTENTS

I. GENERAL GUIDANCE

1. THE LEAVE/STAY DECISION

1.1 GENERAL APPROACH

The classical doctrine held by most mariners is that ocean-going ships should leave ports which are threatened by a hurricane. Despite this natural caution, ships continue to be damaged in port or after leaving port, as a result of encounters with tropical cyclones. This stems mainly from the relative unpredictability of tropical cyclone movement. For example, the average 1970-1979, 24-hour tropical cyclone movement forecast error (Neumann and Pelissier, 1981) represents more than half of the average actual movement of these storms during the 24-hour period. In these circumstances, it is necessary to provide a means for the mariner to come to terms with large errors in the tropical cyclone forecast and to assess the relative risks of remaining in port or putting to sea according to the circumstances of the threat, the facilities of the port and the capabilities of his vessel and crew.

A preliminary evaluation of the balance of these risks along the U.S. Gulf of Mexico and Atlantic coasts is illustrated in Figure I-1. This evaluation relies upon examining four factors:

(1) Local history of hurricane encounters. The risk of a particular port encountering a hurricane depends upon strong seasonal and geographical influences. The heavy solid line of Figure I-1 shows for all seasons how geographical factors concentrate the risk of hurricane encounter at large-scale coastal promontories. The "probability of encounter" here refers to the probability of a tropical cyclone of hurricane intensity passing within 70 n mi of the coast. It is expressed as the % probability to the left of the figure and in terms of return period on the right.

(2) Local predictability of hurricane movement. The risk of misjudging a hurricane threat at the point in time when preparations by large vessels to leave a port should be started (typically 48 hours ahead of destructive force winds or at Hurricane Condition III) is influenced by the size of the forecast error. The dashed line in Figure I-1 shows a pronounced maximum near Philadelphia. This maximum is associated with the special problems of predicting the movement of recurving storms. A minimum value near Key West is associated with storms of lower speed of advance and greater constancy of movement.

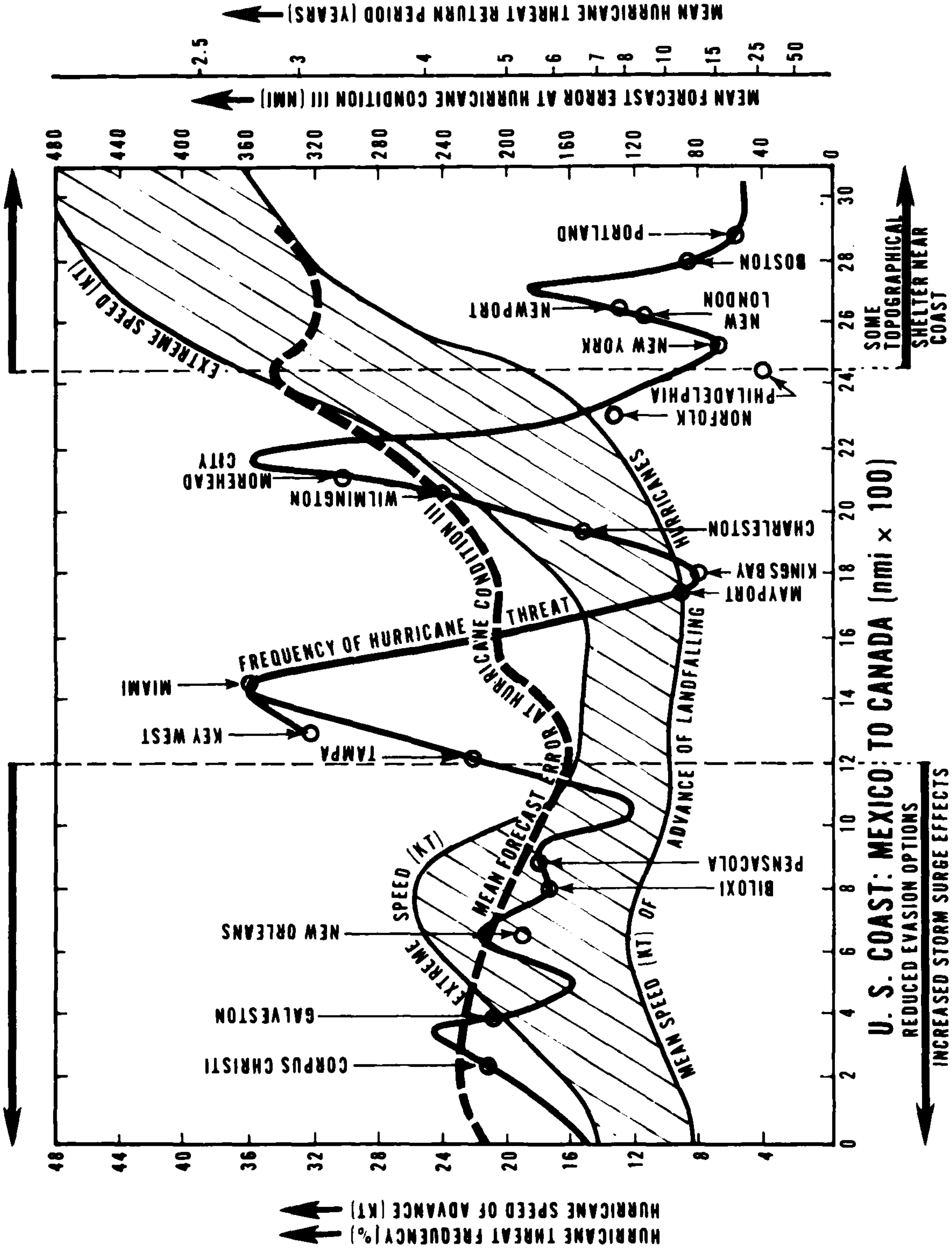

Figure I-1. Factors in the LEAVE/STAY decision at ports threatened by tropical cyclones. (Original sources of data include Ho et al., 1975; Neumann and Pelissier, 1981; and Neumann and Pryslak, 1981.)

(3) Local shelter and security of berths. The risk of a vessel sustaining damage in port in the event of a hurricane strike depends upon the suitability of berthing facilities available to her and the shelter they offer. This cannot be assessed fully on the broad scale but Figure I-1 gives an indication of where topographical shelter may be available. (It has been assumed that shelter may be available if terrain of at least 100 ft elevation is located near the coast.)

(4) Local speed of advance of tropical cyclones. The risk of a vessel sustaining damage at sea increases abruptly as the speed of advance of the storm rises towards the maximum speed capability of the vessel - particularly when the effects of heavy weather on vessel speed are considered. A large range of speeds of advance of tropical cyclones creates the additional possibility than even the well-prepared mariner will be trapped in a late departure dilemma in which insufficient sea room can be gained to exercise evasion tactics successfully. The cross-hatched band of storm speeds in Figure I-1 extends from the mean speed of advance of near-coastal storms to their top 5% extreme speeds.

Large changes in the balance of these four factors affecting the leave/stay decision are evident along the U.S. Gulf and Atlantic coasts. However, in the absence of any well sheltered natural harbors, the hurricane haven qualities of ports along these coasts can only be rated in shades of gray. Such a "gray" rating is especially applicable to the case of Charleston - located on Figure I-1 approximately two thirds along the baseline distance from Mexico to Canada. None of the special coastal features which are highlighted along the baseline (e.g., topographical shelter), apply to Charleston. The continuous curve displaying "Frequency of Hurricane Threat" gives a moderate value of 15% for Charleston on the left-hand scale or a hurricane threat return period of 6 1/2 years on the outer right-hand scale. The broken curve of mean forecast error at Hurricane Condition III gives a moderate value of 220 nm on the inner right-hand scale. Finally, the cross-hatched band displaying speed of advance for near-coastal hurricanes, gives relatively low values for both the mean and extreme speeds of advance of hurricanes affecting Charleston. These values from the left-hand scale are 9 1/2 and 18 kt respectively. They suggest a relatively low risk of damage at sea after evasion from Charleston provided sortie is executed as early as possible.

The particular combination of leave/stay factors in the Mayport area should lead to a very low frequency of both justifiable sorties and sorties conducted because of uncertainties about the tropical cyclone threat. Furthermore, all sorties should carry a low risk of unsuccessful evasion at sea because of the relatively low speeds of advance of near-coastal storms in this area. Ports in the Mayport area therefore have the potential of being fairly good hurricane havens despite their conspicuous lack of shelter, because of the rarity of serious hurricane threats and the prospect of a safe escape to sea when needed.

New York and certain New England ports clearly have the potential to offer good hurricane haven qualities because of the low risk of a hurricane threat in conjunction with the possibility of topographical shelter. Note that the risk of misjudging the threat, due to the large forecast errors associated with storms threatening landfall in this area, is considerable. Furthermore, the risk of sustaining damage in attempting to evade at sea is increased by the high speed of advance of threatening storms. This combination of circumstances should encourage mariners at ports of this coastal region, to regard evasion at sea as a last resort, having exhausted all possibilities of safeguarding their vessels from a hurricane strike at protected berths or anchorages.

Two ports with a high risk of encountering a hurricane threat - Key West and Morehead City - show a large contrast in the remaining factors affecting the leave/stay decision. The threat at Key West appears relatively predictable and easy to evade at sea. However, the combination of low threat predictability and the relatively high speed of advance of near-coastal storms affecting North Carolina, marks Morehead City as a less secure port to occupy during the hurricane season than Key West, and one from which evasion at sea carries a higher risk of damage.

The U.S. Gulf of Mexico coast displays a balance of hurricane haven factors lying between the extremes discussed so far. However, the reduced flexibility in evasion options created by the shape of the Gulf of Mexico biases the leave/stay decision in favor of an early departure, which effectively reduces the predictability of the threat at the time of sortie decision. The large range of possible speeds of advance of tropical cyclones affecting the New Orleans to Pensacola sector of the coast, should encourage even earlier departure. The net effect is that ports in this sector of the U.S Gulf of Mexico coast, should be considered to be as insecure as the conspicuously "high risk" ports typified by Key West and Morehead City. Local factors in the Gulf of Mexico further diminish the security of many ports. For example, the strong impact of storm surge along much of the Gulf coast which, in places, leads to closure of ports due to sudden silting of their long, dredged approach channels. The Texas coast may also be prone to a highly destructive local augmentation of a hurricane's winds immediately after its landfall. The case of Celia's landfall near Corpus Christi in 1970 reveals this effect, which Fujita (1980) has ascribed to the result of the hurricane's interaction with dry, desert air.

Finally, ports which are well set back from the coast on major tidal rivers may be so well isolated from the effects of landfalling hurricanes that, even if they do not offer topographical shelter, they may be considered to be good hurricane havens. For example, the indicated hurricane threat frequency in Figure I-1 for Philadelphia lies below the "coastal" value. Even so, this does not convey the full extent of this port's isolation from the threat because the effects of surface friction and overland dissipation on reducing the strength of the hurricane's windfield have not been considered. In fact, both Philadelphia and Baltimore show good promise as hurricane havens.

1.2 ASSESSING A SPECIFIC HURRICANE THREAT AT PORTS LISTED IN THE HANDBOOK

The above approach to the leave/stay decision emphasizes the importance of coming to terms with the probable error in tropical cyclone movement forecasts. unfortunately, this error is highly variable - even for a specific forecast interval and location - and furthermore, it is not symmetrically distributed

around the forecast position of the storm. Therefore, the application of the forecast error data in Para. 2.4.2 to a specific threat situation could only provide the most rudimentary indication of the probability of destructive weather at the port.

For this reason, the U.S. Navy operates the "Hurricane Wind and Strike Probability" service for each of its major North Atlantic ports and near-coastal USAF bases - a service which allows for the error associated with each tropical cyclone forecast and determines the risk of destructive winds and strike for these locations quantitatively. This is the ideal tool for setting Hurricane Conditions on a rational basis up to 3 days ahead of possible strike (see User's Manual (NEPRF, 1981) for details). At 3 days ahead and beyond, the climatological Near Pass Probability maps included with each port evaluation in this Handbook, can provide advance warning of possible encounter (within 180 n mi) up to a week ahead. For this purpose, a plot of actual and forecast positions of the tropical cyclone should be made on the map appropriate to the time of year (e.g., at Gulfport, Mississippi in September, Figure XI-8 in Section XI of the Handbook should be used). As soon as the position of the tropical cyclone approaches the 3-4 day time line, attention could be diverted to the USN Strike Probability forecast (at Gulfport, MS use the product supplied to Keesler AFB).

Note that the Wind and Strike Probability forecast does not reduce the error in the original forecast and therefore, does not reduce the degree of overwarning which is needed to provide a safeguard against that error. In fact, the % probability threshold values suggested in the User's Manual for setting Hurricane Conditions (see Para. 2.6) imply a higher degree of overwarning than is employed in the coastal warnings issued to the public via the Hurricane Warning Offices. Furthermore, no account is taken in the wind and strike probability forecasts of the effects of shelter or of the dramatic effect which a hurricane's direction of approach can have on its impact at a particular port. For example, both Mayport and Norfolk have experienced numerous threats from storms approaching overland. Few of these have merited ships leaving harbor. However, objective methods for setting Hurricane Conditions on the basis of the forecast "open ocean" winds, would have supported many unnecessary sorties as a result of ignoring the effects of increased friction on the surface wind field. These local considerations are addressed in detail for each port evaluation in the Handbook. The penalty for abandoning a well-rounded evaluation of each hurricane threat, in favor of a purely "objective" approach based upon certain probabilities of strike and 50-kt winds, will be a large increase in unnecessary sorties. Instead, a current tropical cyclone threat should be monitored with the best objective aids available, but also with a keen awareness of the character of the "worst case" threat and the likely impact of lesser threats. For example, at the better hurricane havens, the rare direct landfalling storms are inevitably the "worst case" threats and usually possess conspicuously different track features (e.g., Hurricane Dora of 1964 at Mayport, the 1933 Hurricane at Norfolk and the 1938 New England Hurricane at Newport and New London).

1.3 THE HURRICANE THREAT AT OTHER PORTS

1.3.1 Impromptu Hurricane Haven Evaluation

In considering the security of other Atlantic ports or even when making a decision on leaving or staying at a port under the pressure of a hurricane threat, the separate contemplation of the following factors will be helpful:

(1) Frequency of hurricane threats at the port. Estimate this from the storm frequency at the coast as indicated by the data of Para. 3. Use the appropriate seasonal map.

(2) Predictability of the hurricane threat. Determine the local accuracy of 24- and 48-hour forecasts from Figures I-3 and I-4 and use it to determine the risk of encounter as described below (Para. 1.3.2).

(3) Countermeasures available in port. Consider likely approach directions of threat and compare the security of alternative alongside berths, moorings or anchorages. Consider the possibility of steaming at anchor. Wave and tidal effects will then have least effect, cable strains will be minimized and uncertainties about the strength of piers or moorings are eliminated.

(4) Evasion hazards. Compare likely speed of advance of storm with ship's speed. Compare direction of storm movement in relation to shoal grounds and lee shores. Estimate latest safe departure time for each evasion route.

The balance between hurricane threat frequency (1) and the suitability of port facilities for safeguarding the vessel against damage (3) will determine the mariner's stance towards the threat. Threat frequency varies between wide limits (see Para. 3). For example, all ports along the southern shores of the Caribbean Sea from Venezuela to Costa Rica are relatively secure in all seasons. Further north however, little solace is available except for the embayed western shore of Haiti southeast of Windward Passage.

1.3.2 Assessing Risk Of Encounter With An Approaching Threat And Its Probable Impact

The chances of encountering destructive weather from an approaching tropical cyclone can be estimated by maintaining a plot of its 24- and 48-hour forecast positions. Circles should be drawn round these forecast positions using radii equal to the sum of:

(1) 100 n mi
(2) Double the 24- or 48-hour local forecast error given by Figures I-3 and I-4
(3) (If applicable) The forecast radius of 64 kt winds

Use the initial position of the storm when extracting forecast error data from Figure I-3 or I-4. As long as the port's position lies outside these circles, the chances of encountering destructive weather remain below 10%. Note that for Caribbean storms, this method will overestimate the probability of their landfall along the southern shore from Venezuela to Costa Rica.

Given the uncertainties created by large errors in the tropical cyclone movement forecasts, it is sufficient to judge the probable impact of a hurricane threat from the following simple guidelines:

(1) Storms threatening to make a direct landfall from the ocean within 50 n mi of the port are many times more destructive than storms approaching overland or storms parallelilng the coast.

(2) Starting at gale force winds (34 kt), the force on a moored vessel nearly doubles for every 15 kt extra wind speed up to hurricane force (64 kt) and then more slowly after that.

(3) Tropical cyclones of hurricane intensity carry the added threat of storm tides which typically rise between 5 and 20 ft above normal. Note that this rise in sea level may cause otherwise sheltered berthing areas to become exposed to destructive wave action - especially if the harbor is only protected from the open ocean by low-lying reefs or sandbanks.

(4) The destructive effects of winds, seas and storm tides are most prominent in the right-front quadrant of a storm looking along its direction of movement. This is particularly noticeable to the right of the storm's point of landfall up to a distance of 70 n mi (measured at 90^0 to the direction of its track).

1.4 THE UNEXPECTED TROPICAL CYCLONE THREAT

A sudden unexpected change in the speed or direction of movement of a tropical cyclone, or a change in its intensity, may call for a hasty departure from port in deteriorating weather.

However limitations in manpower onboard, port tug facilities or the state of readiness of the ship's machinery will increase the risk of the the vessel being damaged during departure. Furthermore, the chances of gaining sufficient sea room in heavy weather to avoid damage after leaving port, are also decreased.

The odds for preventing serious damage to the vessel in these circumstances, swing in favor of using the resources available to secure the ship firmly to her berth. These measures should include laying anchors into the channel or basin to hold her away from the pier or wharf face. This is particularly important in preventing damage to both vessel and pier in the event of storm tides flooding the wharf. These tidal effects will require lines to the pier to be tended until the hurricane threat is well passed. Certain merchant vessels may also consider ballasting down if the bottom at the berth is likely to be clear of obstacles.

Under pressure of these circumstances, proceeding to anchor or moor is a less attractive alternative unless both the resources to accomplish the move safely and the assurance of an authenticated hurricane mooring or anchorage, are available.

1.5 HURRICANE CONDITIONS

Both Navy and civil port authorities use the setting of Hurricane Conditions (see Para. 2.6) to announce the recommended state of preparedness to counter an approaching hurricane threat. This announcement includes a statement of the expected timing and impact of the hurricane threat.

Mariners should pace their preparations to counter an approaching threat according to the prevailing Hurricane Condition. Keeping well ahead will allow for any sudden, unexpected changes in the tropical cyclone's behavior.

2. HURRICANE WARNINGS AND FORECASTS

2.1. INTRODUCTION

The Hurricane Warning Service is provided through the cooperation of the Department of Commerce, the Department of Defense and the Department of Transportation. The National Hurricane Center, Miami, Florida is responsible for collating data including the results of aircraft, radar and satellite surveillance, and for developing and issuing hurricane warnings and forecasts for the North Atlantic Ocean including the Caribbean Sea and Gulf of Mexico. The initial warning for each new tropical or subtropical cyclone is issued in consultation with the Naval Eastern Oceanography Center, Norfolk, Virginia.

2.2 MESSAGE FORMAT AND CONTENT

The principal product of the Hurricane Warning Service is the Hurricane Advisory Message; the format and content of which is illustrated in Figure I-2. AVIATION, MARINE and MILITARY Hurricane Advisories all include the first six sections. MARINE and MILITARY advisories carry the additional section on storm tides and precipitation. The MILITARY advisory has a supplementary section giving 48- and 72-hour extended outlook forecasts. The extended outlook is offered for Tropical Storms, Hurricanes and for Tropical Depressions which are forecast to become Tropical Storms within 24 hours.

2.3 MESSAGE DISSEMINATION

The Naval Eastern Oceanography Center, Norfolk, using the MILITARY ADVISORY as guidance, issues messages to U.S. Navy interests titled "Hurricane Warnings." Advisories and Navy Warnings are issued on formation of a tropical or subtropical depression and subsequently at six-hourly intervals at 0400Z, 1000Z, 1600Z and 2200Z.

Additional Special Advisories/Navy Warnings are issued in the event of significant changes in intensity or any changes in motion which significantly affect the threat to coastal areas or U.S. Navy units.

Advisories/Navy Warnings for any particular cyclone will continue until its dissipation or until it adopts the characteristics of - or becomes assimilated by - a frontal or extratropical cyclone.

Identification of an advisory with a particular cyclone is achieved by numbering each new depression consecutively, e.g., TD1, TD2. A check on missing messages is achieved by observing the sequential number series for advisories on each depression, e.g., Advisory Number 1 on TD1, Advisory Number 2 on TD1. When a tropical depression intensifies to storm strength, it is NAMED and the Advisory Number reverts to 1 and starts all over again, e.g., the next Advisory would be designated Advisory Number 1 on Tropical Storm ANITA. Subtropical depressions are dealt with similarly except that those which intensify to become subtropical storms are numbered consecutively instead of being named.

MILITARY advisories are disseminated to DoD users via the Automated Weather Network at Carswell AFB, Texas. NAVEASTOCEAN Navy Warnings are issued via AUTODIN and Channel 8 of the Fleet Multi-Channel Broadcast.

WS F HMC 13
3-8?
PNES H WSOM . 41

U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL WEATHER SERVICE

MILITARY MARINE AVIATION HURRICANE ADVISORY

NOTE *Gusts included when maximum sustained winds reach 50 knots. Use of Quadrants is optional in East and Central Pacific. Twelve hour forecast not included for Atlantic Depressions and Subtropical Storms. *For use in Pacific only*

Subtropical Depression
Subtropical Storm
Tropical Depression ______ Military Marine Aviation Advisory ______ Corrected / Special
Tropical Storm — *Name Number* — *Number*
Hurricane

NATIONAL WEATHER SERVICE ______ (City) ______ (State)

______ (Time) Z ______ (Month) ______ (Day) ______ (Year)

WARNINGS

DEPRESSION, STORM, HURRICANE CENTER LOCATED RELOCATED ______ NORTH ______ WEST AT ______ Z

POSITION EXCELLENT (*Within 10NM*) — BASED ON AF RECONNAISSANCE TIME OF FIX ______ Z
GOOD (*Within 20NM*) — NOAA RECONNAISSANCE TIME OF FIX ______ Z
FAIR (*Within 40NM*) — LAND BASED RADAR — SATELLITE — SYNOPTIC REPORT
ACCURATE WITHIN ______ NM — ACFT RADAR — SHIP REPORT — EXTRAPOLATION

Remarks

PRESENT MOVEMENT ______ OR ______ DEGREES AT ______ KT
DIAMETER OF EYE ______ NM *If known*
MAXIMUM SUSTAINED WINDS ______ KT WITH GUSTS TO ______ KT
RADIUS OF 100 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF 64 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF 50 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF 34 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF SEAS 15 FT OR HIGHER ______ NE ______ SE ______ SW ______ NW
REPEAT CENTER LOCATED RELOCATED NEAR ______ N ______ W AT ______ Z

FORECAST VALID ______ Z ______ N ______ W
MAXIMUM SUSTAINED WINDS ______ KT WITH GUSTS TO ______ KT
RADIUS OF 50 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF 34 KT WINDS ______ NE ______ SE ______ SW ______ NW
FORECAST VALID ______ Z ______ N ______ W
MAXIMUM SUSTAINED WINDS ______ KT WITH GUSTS TO ______ KT
RADIUS OF 50 KT WINDS ______ NE ______ SE ______ SW ______ NW
RADIUS OF 34 KT WINDS ______ NE ______ SE ______ SW ______ NW

AVIATION ADVISORY ENDS HERE

STORM-TIDE OF

HEAVY PRECIPITATION

REQUEST FOR 3-HOURLY SHIP REPORTS

DEPRESSION SUBTROPICAL STORM AND MARINE ADVISORIES END HERE

EXTENDED OUTLOOK FOR INTRAGOVERNMENTAL USE ONLY
OUTLOOK VALID ______ Z ______ N ______ W
MAXIMUM SUSTAINED WINDS ______ KT WITH GUSTS TO ______ KT
RADIUS OF 50 KT WINDS ______ NE ______ SE ______ SW ______ NW
OUTLOOK VALID ______ Z ______ N ______ W
MAXIMUM SUSTAINED WINDS ______ KT WITH GUSTS TO ______ KT
RADIUS OF 50 KT WINDS ______ NE ______ SE ______ SW ______ NW

NEXT ADVISORY AT ______ Z — FORECASTER

Figure I-2. Format of the Hurricane Advisory Message. (From U.S. Department of Commerce, 1981.)

MARINE advisories are broadcast to high-seas shipping according to details found in "Worldwide Marine Weather Broadcast" published by the U.S. Navy and National Weather Service or other maritime weather broadcast lists for the western North Atlantic.

2.4 MESSAGE INTERPRETATION

2.4.1 Terminology

CYCLONE

Generic term referring to a (counterclockwise) rotating closed circulation (N. Hemisphere) irrespective of intensity or type.

DEPRESSION/STORM/HURRICANE

When applied to TROPICAL cyclones, these refer to the following three stages of development and intensity:

(1) Tropical Depression(TD) - A tropical cyclone in which the maximum sustained surface wind (1-minute mean) is 33 kt (38 mph) or less.

(2) Tropical Storm (NAMED) - A tropical cyclone in which the maximum sustained surface wind (1-minute mean) ranges from 34 kt (39 mph) to 63 kt (73 mph) inclusive.

(3) Hurricane (NAMED) - A tropical cyclone in which the maximum sustained surface wind (1-minute mean) is 64 kt (74 mph) or more.

When applied to SUBTROPICAL cyclones, these terms also refer to two stages in development and intensity:

(1) Subtropical Depression - Wind limits as for (1) above (Tropical Depression).

(2) Subtropical Storm - LOWER wind limit as for (2) above (Tropical Storm) but NO UPPER LIMIT.

TROPICAL/SUBTROPICAL/EXTRATROPICAL

The first two adjectives are not used in their normal geographical sense. Tropical Cyclones may develop over both tropical and subtropical water while Subtropical Cyclones develop over subtropical water only.

The meteorological distinction - made possible by satellite surveillance - is that subtropical cyclones possess a hybrid character lying between the Tropical Cyclone and the Extratropical Cyclone.

Subtropical Cyclone features of practical importance to the mariner are as follows:

(1) They are frequently short lived and dissipate without developing beyond the depression stage.

(2) Those which intensify beyond the depression stage occasionally change character to become Tropical Storms. In fact, subtropical storms which intensify to hurricane strength usually adopt tropical characteristics and are then designated as Hurricanes.

(3) Some Subtropical Cyclones are less compact and less intense towards the center than their tropical counterparts and may exhibit a belt of maximum winds as far as 100 miles from their center (compared with a radius to maximum winds in tropical cyclones typically close to 20 miles).

The Extratropical Cyclone is the much larger scale, usually less intense, frontal cyclone of middle latitudes. These cyclones lie outside the scope of the Hurricane Warning Service - although many Tropical and a few Subtropical Cyclones adopt Extratropical characteristics or merge with existing Extratropical cyclones before dissipating, if they move sufficiently far north to encounter cold air.

TROPICAL WAVE/TROPICAL DISTURBANCE

These terms are not normally employed in the Hurricane Advisories but may appear in related products of the Hurricane Warning Service such as the Tropical Cyclone Discussion and the Tropical Weather Outlook.

The Tropical Wave is a minor cyclonic disturbance in easterly tradewinds which could develop into a Tropical Depression but lacks evidence of a closed circulation.

Tropical Disturbance is a generic term which includes all of the foregoing, i.e., Tropical Wave, Cyclone, Depression, Storm, Hurricane and Subtropical Depression or Storm.

2.4.2 Limits of Hurricane Warning and Forecast Accuracy

A clear distinction must be made between "actual" information and the more speculative "forecast" information in the Hurricane Advisory Message (see Figure I-2).

(1) "Actual" information on the location and present movement of the cyclone is now of outstanding reliability even when the cyclone is well offshore because satellite images are available every 30 minutes from Geostationary Satellite (GOES) surveillance for all sea areas affected by the North Atlantic Hurricane. The average initial positioning error in routine Hurricane Advisories for the 10-year period 1970-1979 was only 20 n mi (Neumann, 1980). Satellite surveillance also permits the estimation of tropical cyclone intensity (Dvorak, 1975).

If a tropical cyclone is threatening landfall along the United States coast, further improvement in the "actual" data contained in the Hurricane Advisory is provided by aircraft surveillance and also by land-based radar. Hourly updates of the actual position of any tropical cyclone within 200 n mi of land-based radar, are issued by the National Hurricane Center to the public.

(2) "Forecast" information on the location, movement and intensity of tropical cyclones, in comparison with "actual" data, is distinctly inaccurate. In fact, the forecasting of tropical cyclone movement alone is a formidable problem as it depends upon the interaction between several essentially independent scales and levels of atmospheric motion over a vast - mainly oceanic area. Even in the relatively well-populated Caribbean area, the network of vital upper air observing stations is sparse and in recent years, is showing signs of deteriorating. Despite these difficulties, improvements in satellite surveillance and forecast techniques have maintained a small but continued improvement in forecast accuracy.

Average forecast position errors escalate rapidly as the forecast interval increases:

FORECAST INTERVAL;	12	24	48	72 (HOURS)
AVERAGE POSITION ERROR:	51	109	244	377 (NAUTICAL MILES)

(For period 1970-1979; from Neumann and Pelissier, 1981)

In fact, these averages reflect a serious weakness in movement forecasting - the limited ability to predict recurvature and the subsequent tracks and speeds of recurving storms (i.e., those which change from a westerly track to a northeasterly one - often aligned with the east coast of the U.S.). This weakness leads to considerable regional inequality in forecast errors. Figures I-3 and I-4 show the regional distribution of average errors in 24- and 48-hour forecasts, respectively. Minimum errors appear in the Caribbean and Gulf of Mexico. The large errors associated with recurving storms become disproportionately large north of Florida beyond a forecast interval of 48 hours. Consequently, the 48- and 72-hour forecasts are considered to be unsuitable for dissemination to the public.

2.5 HURRICANE LANDFALL (OR STRIKE) FORECASTS

To the commanding officer of a ship in harbor, the threat posed by a hurricane is more forcefully expressed by its chances of making a landfall nearby than by the chances of a near overland pass or a near pass offshore.

Forecast aids which specifically address the landfall event are as follows:

2.5.1 Coastal Warnings for tropical storms and hurricanes threatening to cross the coast of the U.S. are issued to the public by the National Hurricane Center through the local Hurricane Warning Offices. They specify the coastal extent of the warning in order that defenses against damage and perhaps evacuation, can be implemented. Two levels of warning are employed: the "Hurricane Watch" is a preliminary alert that a hurricane may threaten a specified portion of the coast and is issued approximately 36 hours before landfall could occur. The second level is the "Hurricane Warning" which indicate that hurricane conditions are expected within 24 hours along a specified length of coastline - usually lying within the coastal area for which a Hurricane Watch had previously been issued. The Hurricane Warning is usually issued between 12 and 24 hours in advance of landfall. This service is aimed at providing the best compromise between timeliness and accuracy for civil defense purposes and therefore its warnings may be too late to allow ocean-going vessels to get underway and complete a successful evasion in open water. In the period 1970-1979, Hurricane Warnings were issued with an average lead time of 19 hours for the 23 tropical storms or hurricanes which made a direct landfall along the United States coast. The average landfall error of 39 n mi for landfall forecasts during this period is impressively low (Neumann and Pelissier, 1981).

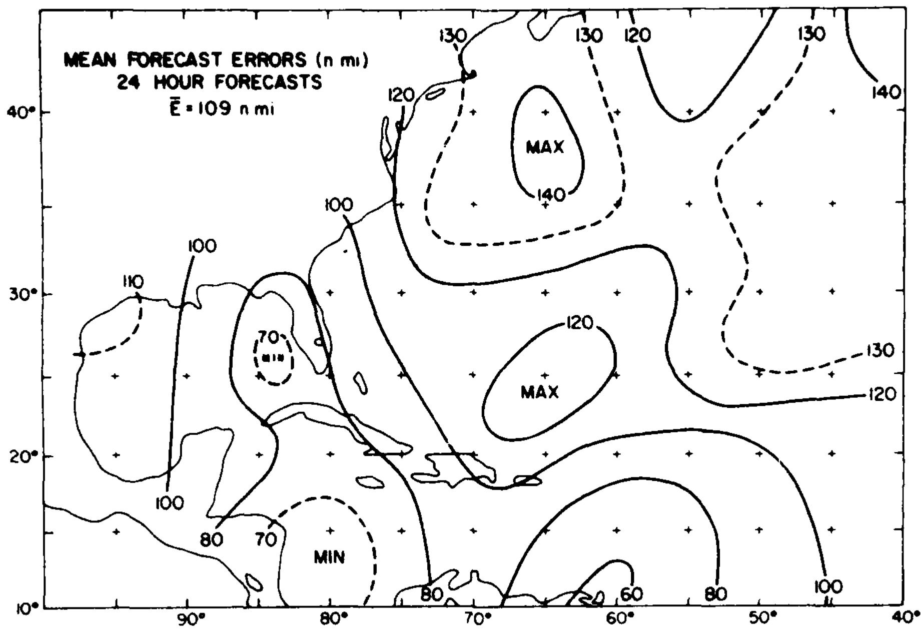

Figure I-3. Geographical variation in the average 24 hour tropical cyclone forecast error. Ē is the average error for all 24 hour forecasts. Errors are relative to storm's initial position. (From Neumann and Pelissier, 1981.)

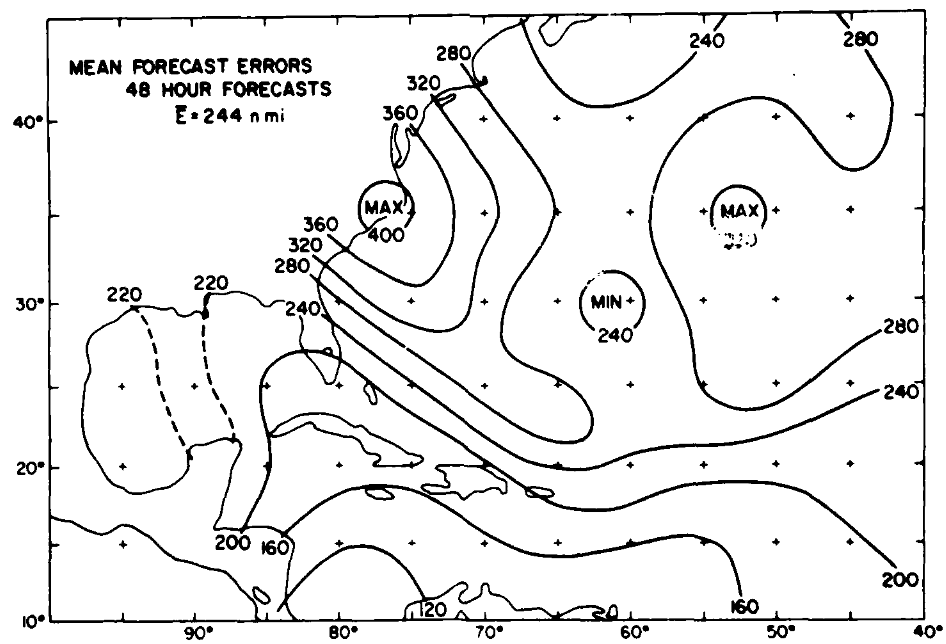

Figure I-4. Geographical variation in the average 48 hour tropical cyclone forecast error. Ē is the average error for all 48 hour forecasts. Errors are relative to storm's initial position. (From Neumann and Pelissier, 1981.)

Cautious optimism is needed in assessing the accuracy of landfall forecasts because it depends critically upon the angle between the storm's approach and the coastline. Perpendicularly landfalling storms will usually show the least error - a characteristic of most landfalling storms in the Gulf of Mexico where movement forecast errors are also small. Given that at least 3/4 of all U.S. landfalling hurricanes occur in the Gulf of Mexico (a figure borne out for the 1970-1979 period cited above), it is clear that in the average landfall error figures, the well-forecast Gulf of Mexico cases overpower the minority of ill-forecast landfall cases in other regions (e.g., Tropical Storm Heidi crossed the coast at Bangor, Maine in 1971, 130 n mi from the forecast landfall point). In general, large errors in landfall forecasts can be expected from Miami to Maine with the worst combination of circumstances occurring in the north.

2.5.2 U.S. Navy Strike Probability Forecast Service. This service which has been in operational use in the western Pacific since 1979, and in the North Atlantic since 1981, is aimed specifically at the mariner, both at sea and in harbor, who is faced with a tropical cyclone threat. It offers a dramatic improvement on the established Navy practice of drawing "danger areas" based upon the sum of two distances: The forecast radius of 30-kt winds; and a fixed average position error determined solely by the forecast interval. The "danger area" method provides no quantitative indication of the risk of say, encountering 30-kt winds at the "danger area" boundary because it takes no account of the fact that errors in some forecasts are much larger than others.

The Strike Probability forecasts uses a statistical analysis which estimates the error of each individual tropical cyclone forecast and from it, calculates the % probability of a specific location being struck by the cyclone at each forecast interval out to 72 hours. In its latest form denoted "Wind and Strike Probability Forecast," the % probability of 30- and 50-kt winds is also computed.

Two versions of the service are available: one which applies to a moving datum is employed ashore as a tool in the Optimum Track Ship Routing Service and is also employed aboard a' craft carriers; the second applies to a fixed datum to assess the Tropical Cycione threat at key Navy locations and coastal USAF bases. Figures I-5 and I-6 show shore locations serviced in the North Atlantic area.

2.5.3 Near Pass Probability. The maps of Near Pass Probability included with each port evaluation in the Handbook are for providing advance warning of a tropical threat when it is still beyond the range of real-time forecasts such as the Hurricane Advisories or Navy Strike Probability forecasts. They are therefore of value when a tropical cyclone is more than 3 days' and up to 6 days' movement from a port, but are less skillful than real-time forecasts at 72-hours range and less.

2.6 SETTING HURRICANE CONDITIONS

The setting of Hurricane Conditions of readiness is carried out at Navy and civil ports in consultation with meteorologists. The procedure serves mostly as a landfall forecast - usually based on the Military Advisory message and therefore extending to 72 hours before expected landfall - and also as a framework

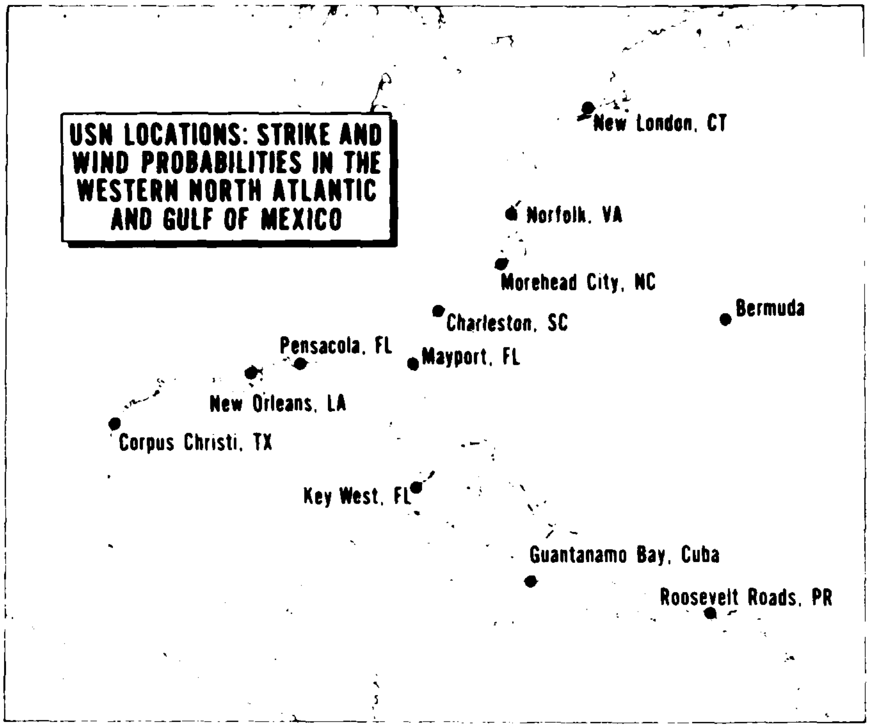

Figure I-5. Ports serviced by U.S. Navy Strike and Wind Probability forecasts. (From N.E.P.R.F., 1981.)

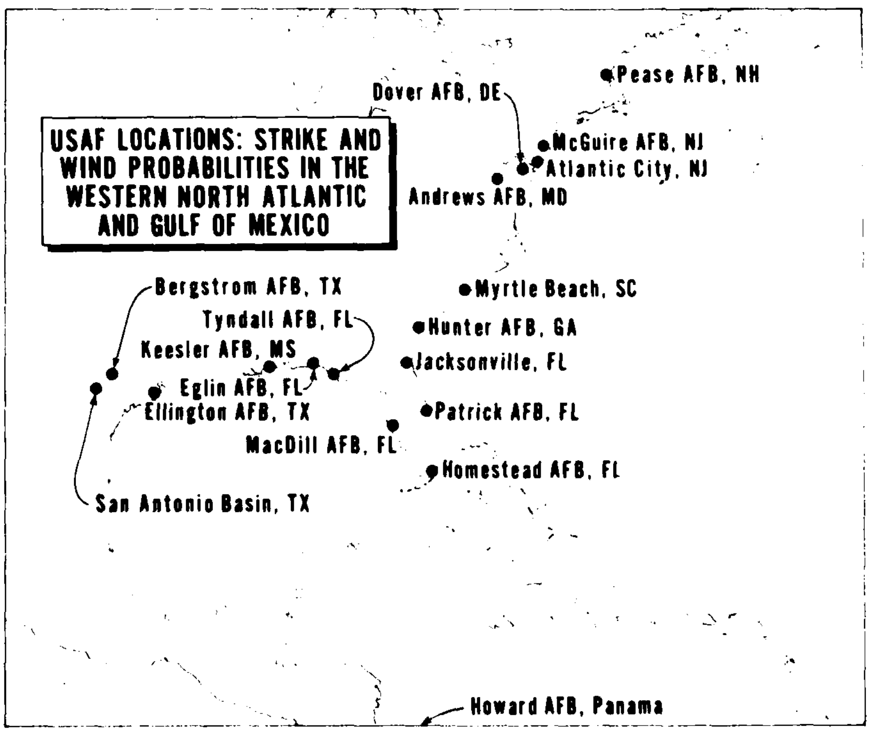

Figure I-6. Near-coastal USAF bases serviced by U.S. Navy Strike and Wind Probability forecasts. (From N.E.P.R.F., 1981.)

for linking a staged schedule of hurricane countermeasures with specific levels in a mounting hurricane threat. Along the U.S. coast, Hurricane Conditions will be set by Navy or Coast Guard authorities according to similar rules. Timings implied by specific Hurricane Conditions may vary, because some Coast Guard authorities observe additional intermediate stages in their schedule at 36 and 18 hours. These correspond with the National Weather Service coastal warnings.[1]

Navy instructions for setting Hurricane Conditions are based upon the following schedule (Dept. of the Navy, 1974):

<u>Hurricane Conditions IV</u>[2]: Trend indicates a possible threat of destructive winds of force indicated within 72 hours. Review hazardous and destructive weather implementation plans.
<u>Hurricane Condition III</u>[2]: Destructive winds of force indicated are possible within 48 hours. Take preliminary precautions.
<u>Hurricane Condition II</u>[2]: Destructive winds of force indicated are anticipated within 24 hours. Take precautions that will permit establishment of an appropriate state of readiness on short notice.
<u>Hurricane Condition I</u>[2]: Destructive winds of force indicated are anticipated within 12 hours or less.

Considerable enlargement of the precautions demanded at each stage is given in both Navy and civil Hurricane Preparedness plans according to local circumstances. An additional, low state of preparedness, designated Hurricane Condition V may, in certain areas, be set automatically at the beginning of the Atlantic hurricane season (1 June) and rescinded at the end of the season (1 December). At ports listed in the Handbook, the climatological Near-Pass Probability maps provide the possibility of setting Hurricane Condition V on the basis of a threat which is specifically directed towards the port. Suitable criteria for setting Hurricane Condition V on the basis of the Near-Pass Probability maps are as follows:

"Hurricane Condition V should be set when:

<u>EITHER</u>: (1) Any tropical cyclone (irrespective of its intensity) forms within or moves inside the 3% probability envelope. If its position inside this envelope lies inside the 4 1/2-6 day time line, higher conditions of readiness may have to be considered (see below).

<u>OR</u>: (2) Any tropical cyclone (irrespective of its intensity) forms within or moves within a radius of 360 n mi from the port, even though outside the 3% probability envelope...."

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[1]The Hurricane Watch is issued approximately 36 hours before landfall. The Hurricane Warning is issued approximately 18 hours before landfall.

[2]Or storm, gale as appropriate.

If the tropical cyclone continues to move towards the 3-4 day time line within the 3% probability envelope or if it threatens to continue closing its range within 360 n mi even though it lies outside the 3% envelope, the setting of Hurricane Condition IV should be considered. However, at this stage, attention should be diverted towards real-time forecasts.

There are two problems in determining whether the storm will have sufficient impact at the port to justify setting higher conditions of readiness: The large errors associated with tropical cyclone forecasts; and the influence of local factors which affect the impact of storms.

The Navy Wind and Strike Probability forecast is the recommended approach towards the first problem. Note that it does not reduce the error in the original forecast and therefore does not reduce the degree of overwarning needed to compensate for that error. As a starting point, the Users Manual (NEPRF, 1981) suggests the following threshold values of "time integrated probability" for strike[3], at which each Hurricane Condition should be set:

Hurricane Condition	Threshold Value of "Time-Integrated Probability" of Strike
IV	Greater than or equal to: 5% within 72 hours
III	Greater than or equal to: 10% within 48 hours
II	Greater than or equal to: 20% within 24 hours
I	Greater than or equal to: 30% within 12 hours

It is further recommended that these objective criteria for setting higher conditions of readiness, be regarded as <u>minimum</u> criteria. Further consideration should be given to the individual circumstances of the current threat before revising the prevailing state of readiness. Otherwise a high degree of overwarning will be perpetrated. Details of these local considerations are supplied for each port listed in the Handbook. An example illustrating the influence of local factors on the setting of Hurricane Conditions without employing the Strike Probability forecast, appears in the Appendix to Section IV of the Handbook entitled "Proposed Rationale for Setting Hurricane Conditions at Key West." Given the added facility of the Strike Probability forecast, a simpler set of criteria can be devised in which the threshold values of Wind or Strike Probability at which Hurricane Conditions are set, are adjusted according to the local factors affecting the impact of a hurricane threat. For example, at Mayport, Jacksonville and King's Bay, lower threshold values for strike or 50-kt winds should be demanded of storms threatening to parallel the east coast after swinging northward from the Antilles (e.g., Hurricane David, 1979) than for storms approaching overland from the Gulf of Mexico. Still lower threshold values of strike probability should alert these ports to possible danger in the rare case of storms with more northerly courses which threaten to make direct landfall along this section of the coast (e.g., Hurricane Dora, 1964).

[3]A hurricane "strike" in this context signifies that the port lies within 75 n mi to the right of the hurricane's center (looking along the direction of the storm's track) or within 50 n mi to the left of the storm's center.

3. ATLANTIC TROPICAL CYCLONES: 1899-1978

The following figures illustrating the behavior of Atlantic tropical cyclones have been extracted from "Frequency and Motion of Atlantic Tropical Cyclones," by C. J. Neumann and M. J. Pryslak published in March 1981 as NOAA Technical Report NWS 26 to which reference should be made for any detailed study. The 12 figures selected here, divide the Atlantic Hurricane Season into 3 periods:

- Figures I-7, A, B, C and D refer to Early Season Storms from 1 May to 15 July.
- Figures I-8, A, B, C and D refer to Mid-Season Storms from 16 July to 20 September.
- Figures I-9, A, B, C and D refer to Late Season Storms from 21 September to 30 November.

Seasonal changes in Atlantic tropical cyclone behavior are strikingly revealed by the subdivisions used above. For example, Early Season Storms mostly originate in the west Caribbean Sea and Gulf of Mexico while Mid-Season Storms mostly originate in the main basin of the tropical Atlantic Ocean and show a much stronger westerly component in their movement. The Late Season witnesses a more gradual change in which tropical cyclone activity in the main basin of the tropical Atlantic Ocean declines but is accompanied by a revival in such activity in the Caribbean Sea and Gulf of Mexico. Although the movement of Caribbean and Gulf storms in Late Season resembles Early Season activity in this area, there is a larger proportion of tropical cyclones of full hurricane intensity later in the year because of the larger reservoir of heat available in the ocean towards the end of the season. Tropical cyclone activity is rare in the Atlantic Ocean and its adjacent seas outside the period 1 May to 30 November.

The 'A' and 'B' figures in each seasonal group illustrate tropical cyclone MOTION. The tropical cyclone tracks of the 'A' figures refer only to those which reached hurricane intensity. However these tracks are also characteristic of the tropical storms during the same seasonal period and the reduced number of tracks shown, improves clarity. The average motion vectors in the 'B' figures refer to both hurricanes and tropical storms - little significant differences exists between the average motion of the two groups.

The 'C' and 'D' figures in each seasonal group illustrate tropical cyclone FREQUENCY[4] - estimated from the 80-year period 1899-1978, and expressed as the number of tropical cyclones per 100 years. Important differences exist between the frequency of tropical storms and hurricanes - particularly in Early and Late Seasons (compare corresponding 'C' and 'D' figures).

The information in the following figures is provided for the advance planning of evasion route options and perhaps the impromptu estimation of hurricane haven potential of ports not listed in the Handbook (see Para. 1.3.1).

The average motion vectors should NOT be used determine the probable short-term movement (3 days or less) of a tropical cyclone when real-time forecast information is available.

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[4]Tropical cyclone frequency at a point was determined from the number of hourly storm positions falling inside 4,914 circles of 75 n mi radius distributed on a regular grid measuring 60 n mi on a side (circles centered on adjacent grid points overlap to some degree).

Figures I-7,-8,-9 are grouped on facing pages for ease of comparison - see pp I-20 to I-25.

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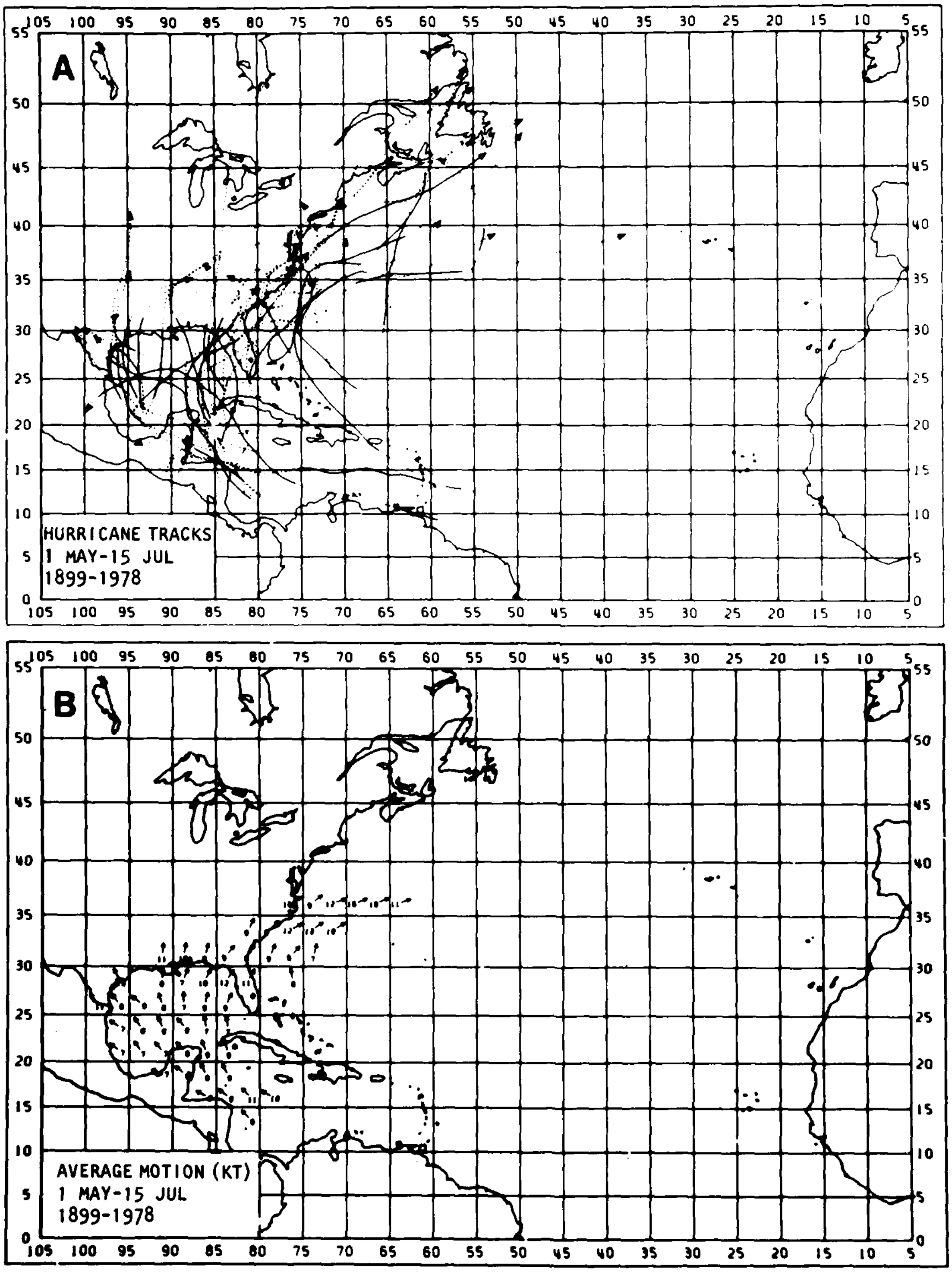
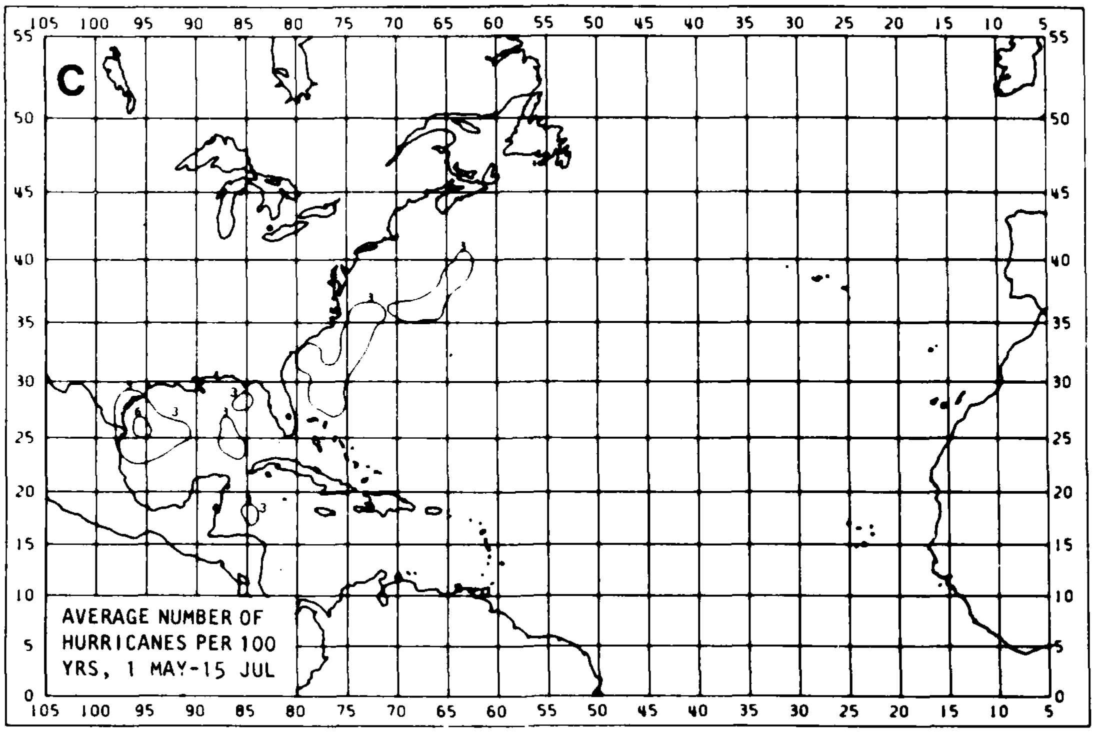


Figure I-7 A,B. Early season storm motion, 1 May-15 July. Note preponderance of Caribbean and Gulf storms and the strong northward component of their movements.



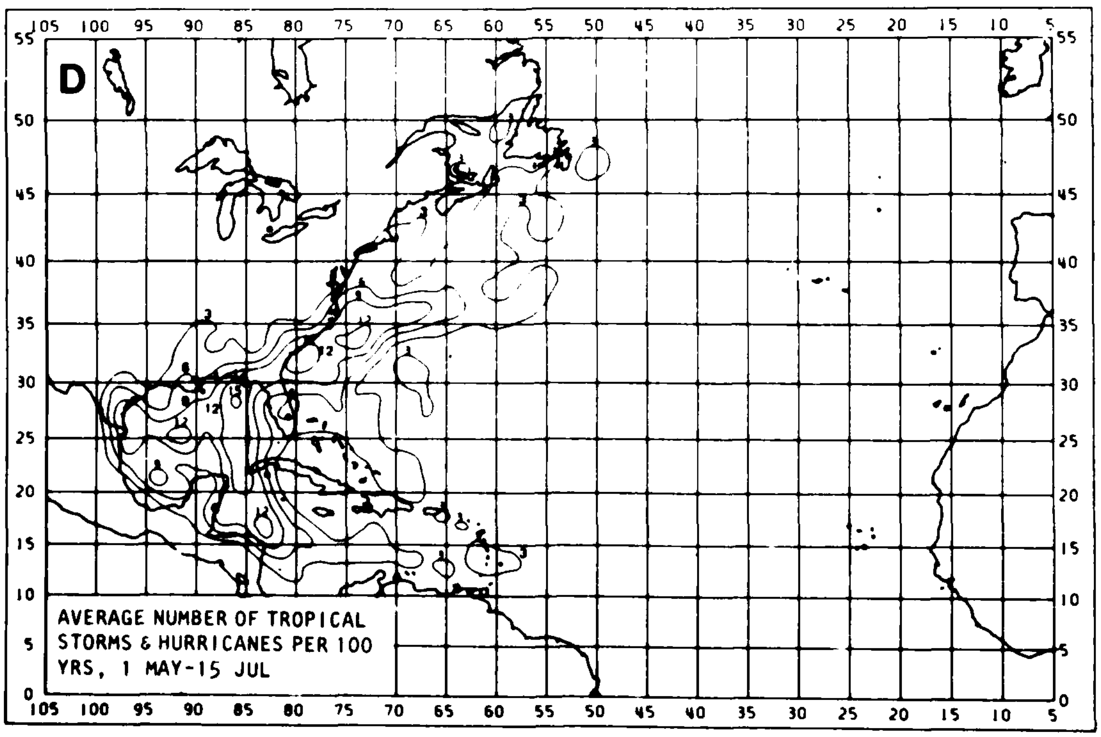


Figure I-7 C,D. Early season storm frequency, 1 May-15 July. Note the small proportion of tropical cyclones reaching hurricane intensity.

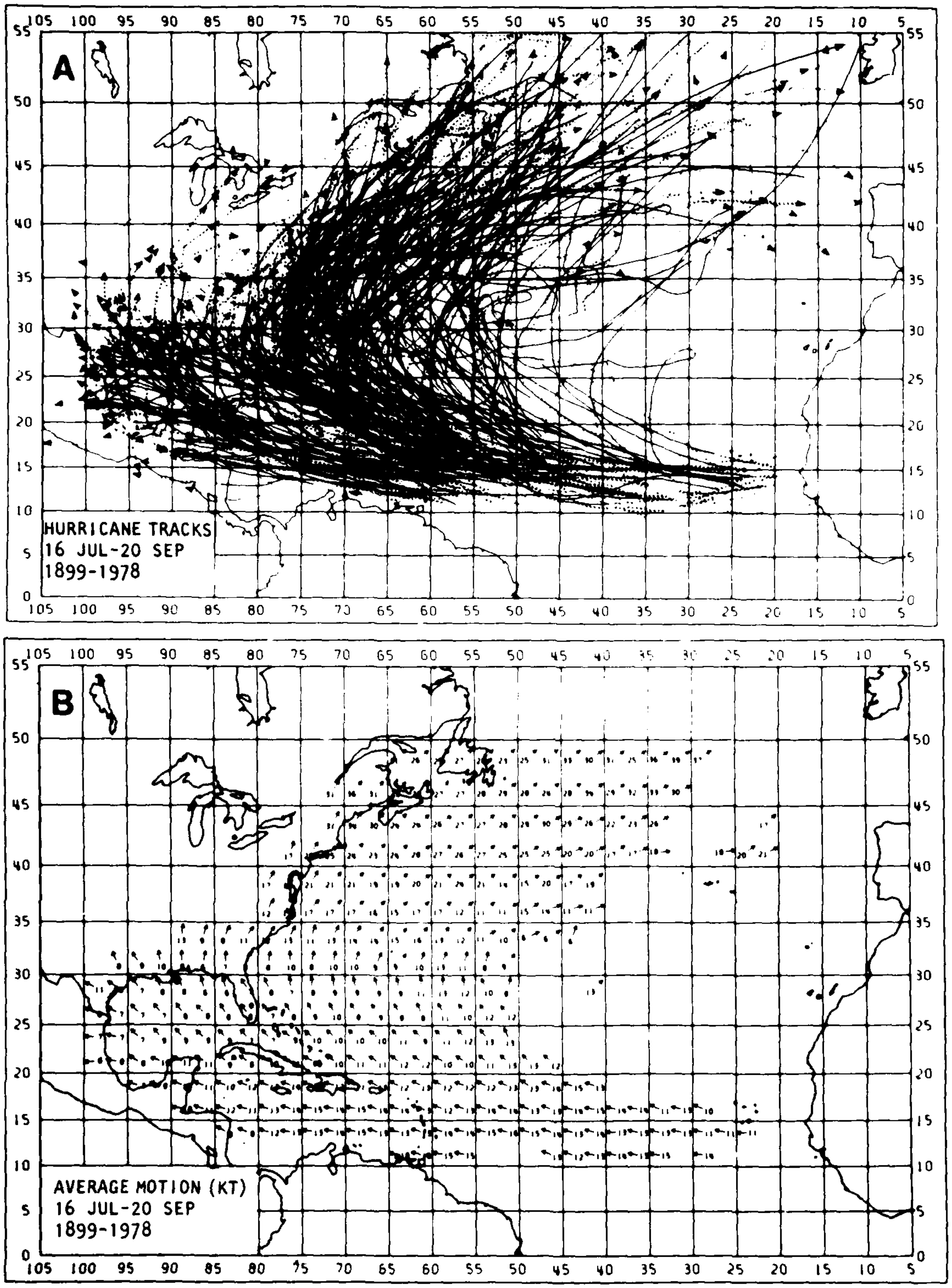


Figure I-8 A,B. Mid season storm motion, 16 July-20 September. Note the preponderance of storms originating in the main basin of the tropical Atlantic Ocean.

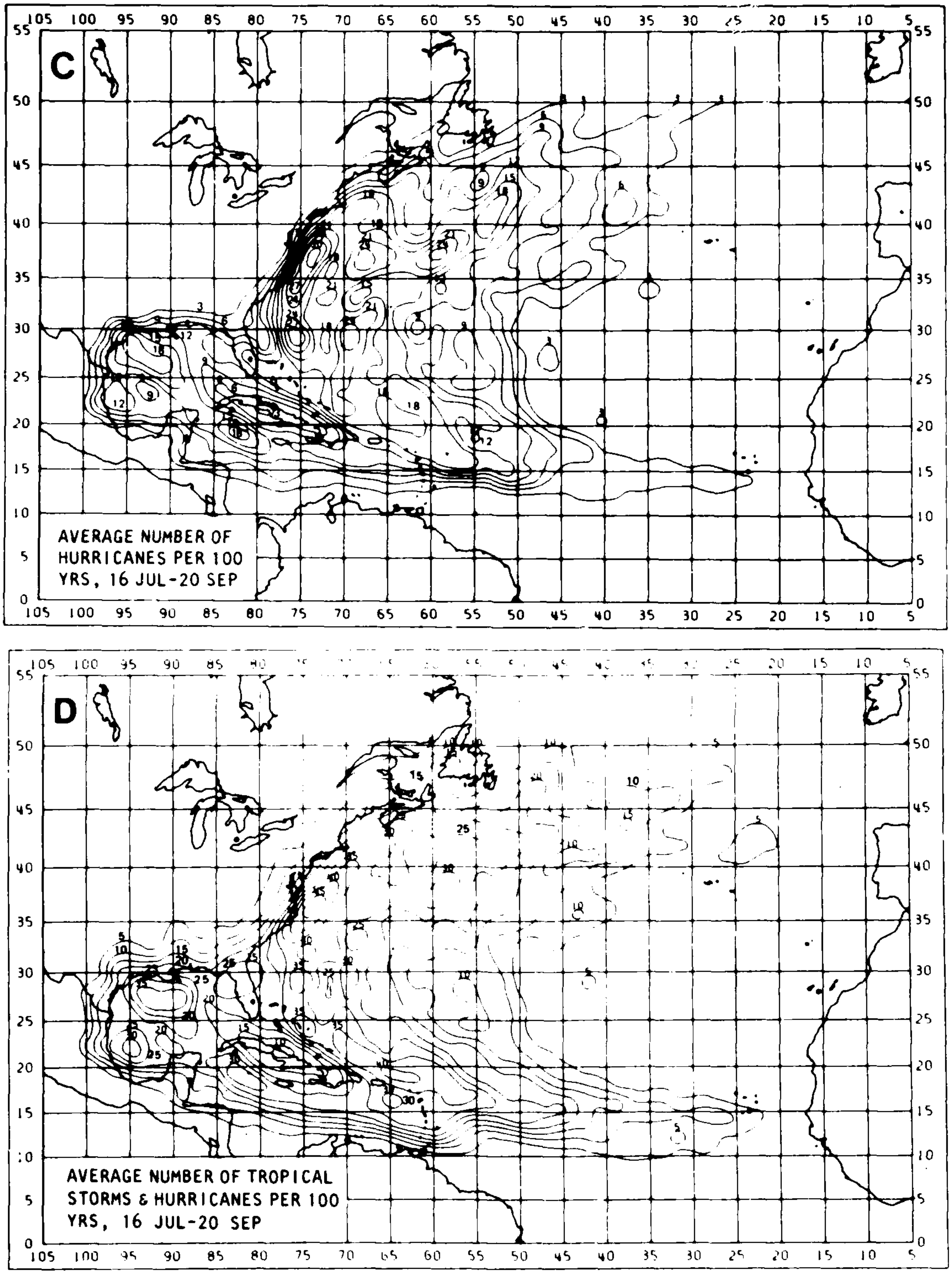


Figure I-8 C,D. Mid season storm frequency, 16 July-20 September. Hurricane and tropical storm distributions correspond closely.

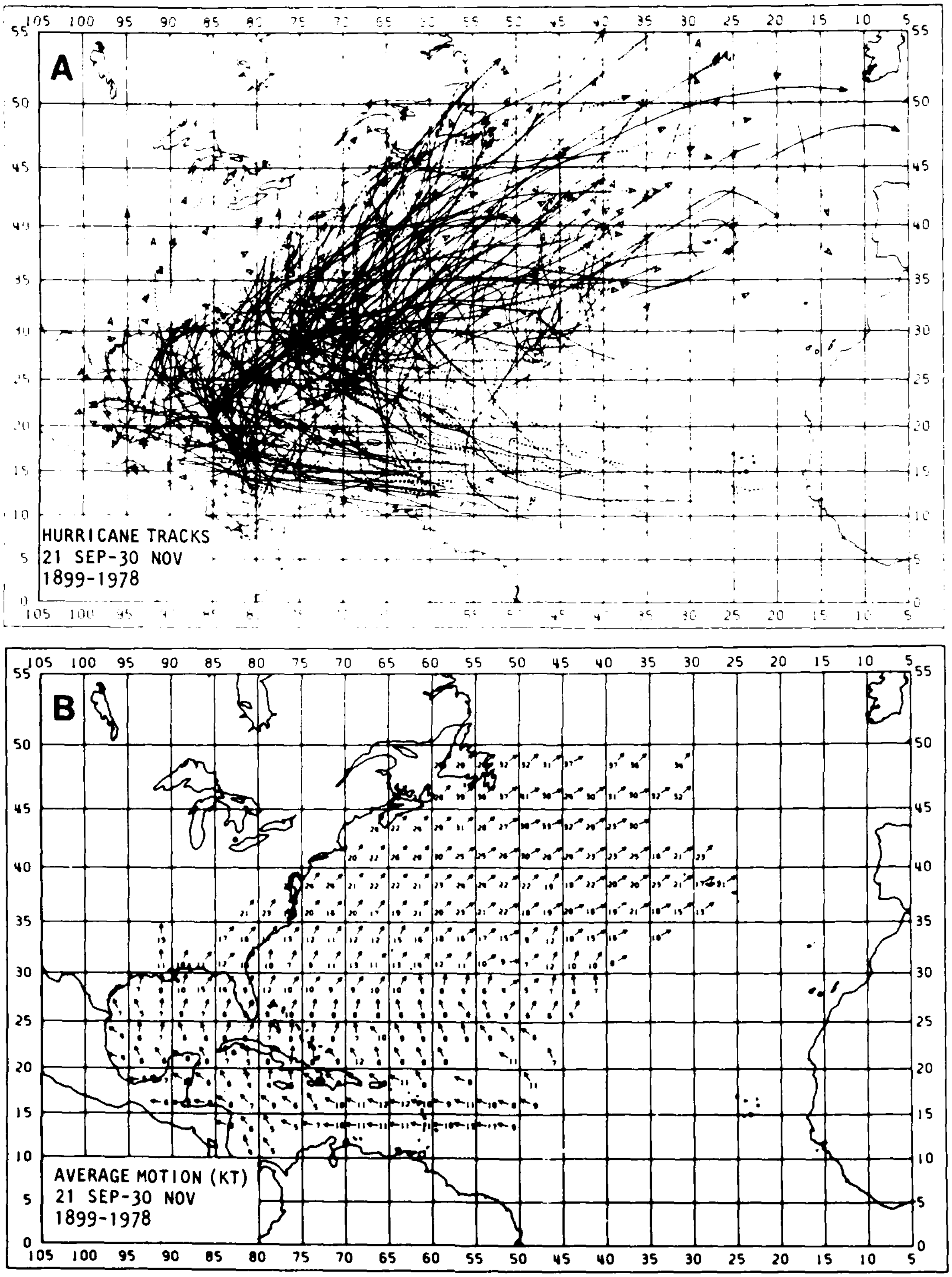


Figure I-9 A,B. Late season storm motion, 21 September-30 November. Note revival of storm formations in the Caribbean and Gulf and the strong northerly component of their movements.

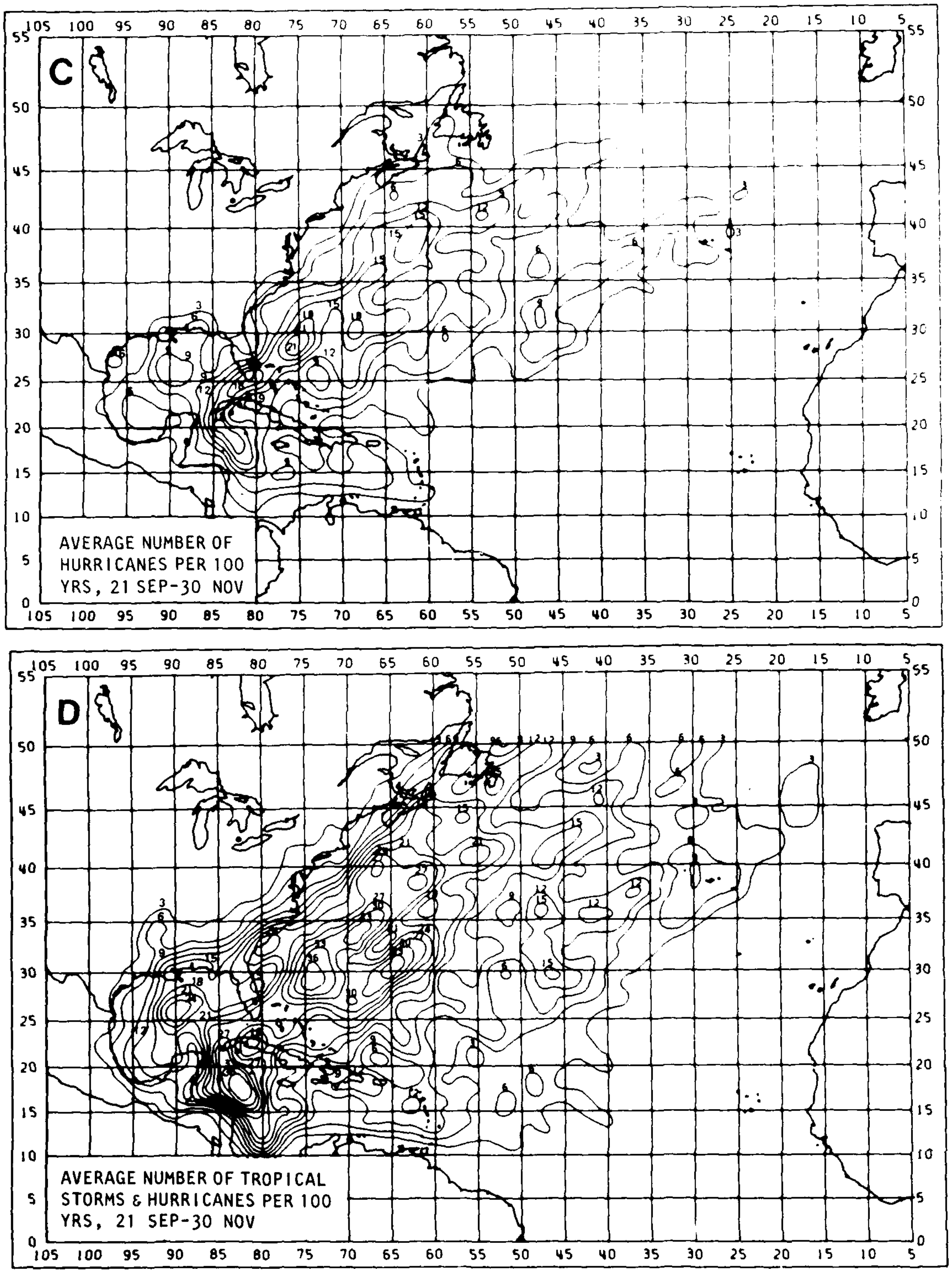


Figure I-9 C,D. Late season storm frequency, 21 September-30 November. Note dramatic reduction in landfalling storms along the east coast of the U.S. and the strong emergence of hurricane-intensity tropical cyclones through the Yucatan and Florida Straits.

II: CONTENTS

II. NORFOLK, VIRGINIA

SUMMARY

Tropical cyclones capable of maintaining sustained winds of hurricane force (greater than 63 kt) at the Norfolk harbors are a rarity. This stems from the particular combination of Norfolk's high latitude and the orientation of the coastline which provides protection from the more vigorous tropical cyclones. Nevertheless, none of the harbors in the Norfolk area is a haven during hurricane force winds. All ships should evade at sea, go to anchor, or if at sea, seek shelter elsewhere. In severe tropical storm conditions (winds 50-63 kt), the harbors will provide shelter for most ships, but ships with large sail areas and especially carriers should evade at sea. For ships likely to suffer damage in an attempt to evade at sea, the hurricane anchorages in Chesapeake Bay are available. Smaller vessels, fishing boats and sailing craft, and those ships disabled by maintenance should seek shelter in the Norfolk Naval Shipyard or other locations along the southern branch of the Elizabeth River. These conclusions are mainly based on the following factors:

(a) The topography of the area is entirely flat and provides very little sheltering from the wind.

(b) There is good shelter from wave action in all the harbors except for the Naval Station with westerly winds.

(c) There is a significant threat of storm surge.

It is recommended that ships take action as described above at an early stage in the threat situation due to the particularly difficult evasion routes that are likely to be available.

1. GEOGRAPHIC LOCATION

Figure II-1 shows the general areas of Norfolk, situated in the southeast corner of the State of Virginia at the southern end of Chesapeake Bay. The major local naval activities of the Norfolk complex are depicted.

Figures II-2, II-3, and II-4 are close-ups of the areas outlined in Figure II-1 showing the three harbor areas covered by this study: Naval Station, Norfolk; Naval Amphibious Base, Little Creek; and Norfolk Naval Shipyard.

This hurricane haven evaluation was prepared by LT CDR G.A. Stevenson, RN, Royal Navy Exchange Officer at NAVENVPREDRSCHFAC.

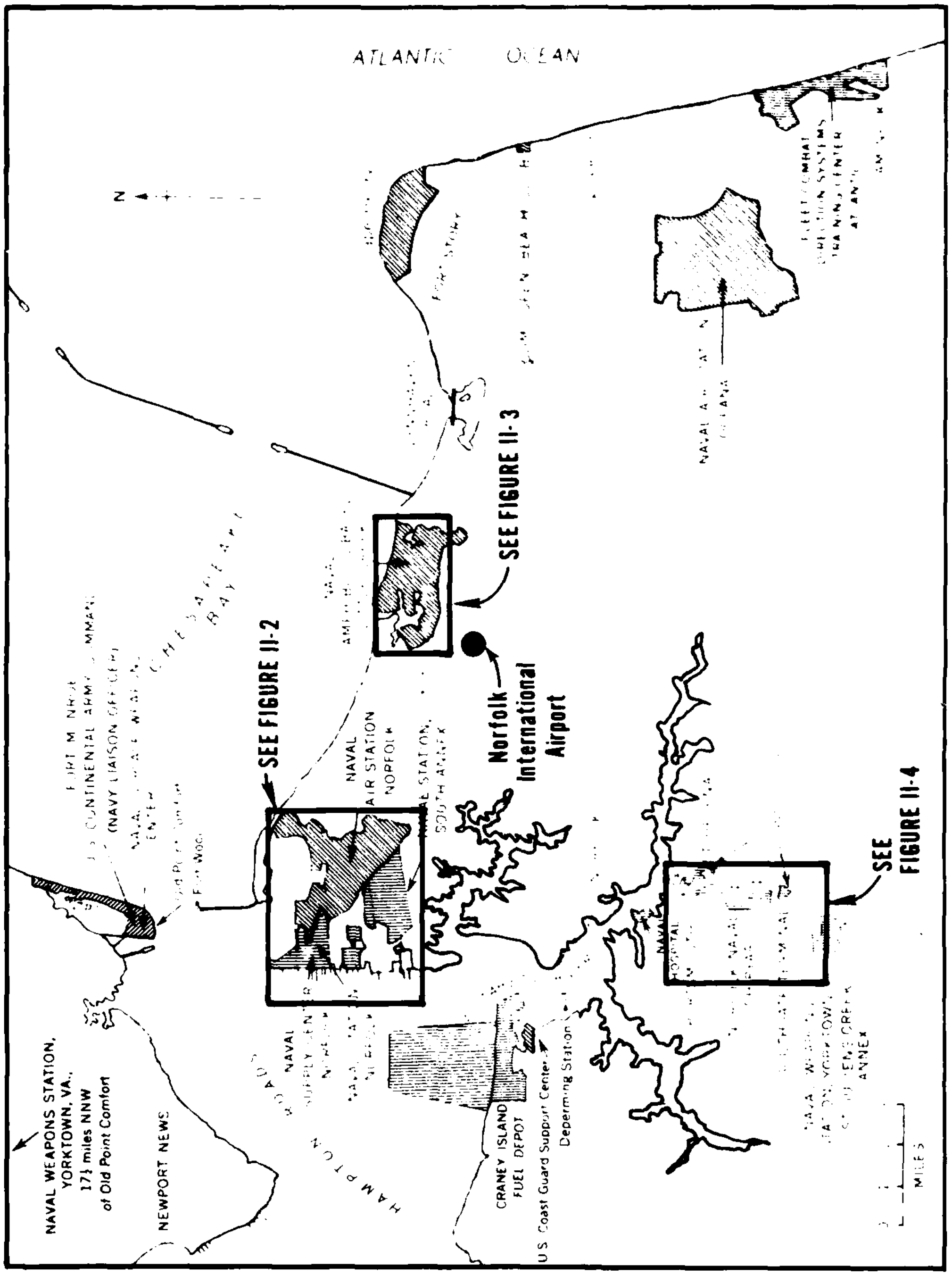


Figure II-1. Norfolk and vicinity showing locations of naval activities and places mentioned in text.

2. THE HARBORS AND THEIR FACILITIES

2.1 NAVAL STATION, NORFOLK (Figure II-2)

Norfolk Naval Station lies at the eastern shore of Hampton Roads. Hampton Roads is a natural tidal basin formed by the confluence of the James and Elizabeth Rivers. The entrance to Hampton Roads for all deep draft ships lies between Old Point Comfort and Fort Wool (see Figure II-1). Not only is Hampton Roads the gateway to the Naval Station, but also provides access to commercial and naval activities at Norfolk and Portsmouth on the Elizabeth River, extensive shipbuilding and cargo handling facilities at Newport News and many smaller facilities and marinas along the James and Elizabeth Rivers. The whole area therefore is extremely busy with marine traffic.

The Norfolk area, being the largest concentration of naval activity on the east coast of the United States, has a large number of berths, anchorages, facilities and services available. The reader is referred to the following publications for complete details:

DMA Hydrographic/Topographic Center Publication 940 Chapter 5, Fleet Guide Hampton Roads.
Chart 12221, Chesapeake Bay Entrance.
Chart 12245, Hampton Roads.
U.S. Department of Commerce, United States Coast Pilot 3, Atlantic Coast: Sandy Hook to Cape Henry.

2.2 NAVAL AMPHIBIOUS BASE, LITTLE CREEK (Figure II-3)

Little Creek is a small inlet on the southern shore of Chesapeake Bay approximately 10 miles east of the naval station (see Figure II-1). The base is used only by amphibious ships and shallow draft vessels since the limiting draft is only 18 ft (5.5 meters). The reader is referred to the following publications for details of the harbor and its facilities:

DMA Hydrographic/Topographic Center Publication 940 Chapter 5, Fleet Guide to Hampton Roads.
Chart 12221, Chesapeake Bay Entrance.
Chart 12255, Naval Amphibious Base - Little Creek.
U.S. Dept. of Commerce, United States Coast Pilot 3, Atlantic Coast: Sandy Hook to Cape Henry.

2.3 NORFOLK NAVAL SHIPYARD (Figure II-4)

The Norfolk Naval Shipyard is situated along the southern branch of the Elizabeth River, approximately five miles south of the naval station. It can accept ships of any draft at any stage of the tide. Again, the reader is referred to the following publications for details of the harbor and its facilities:

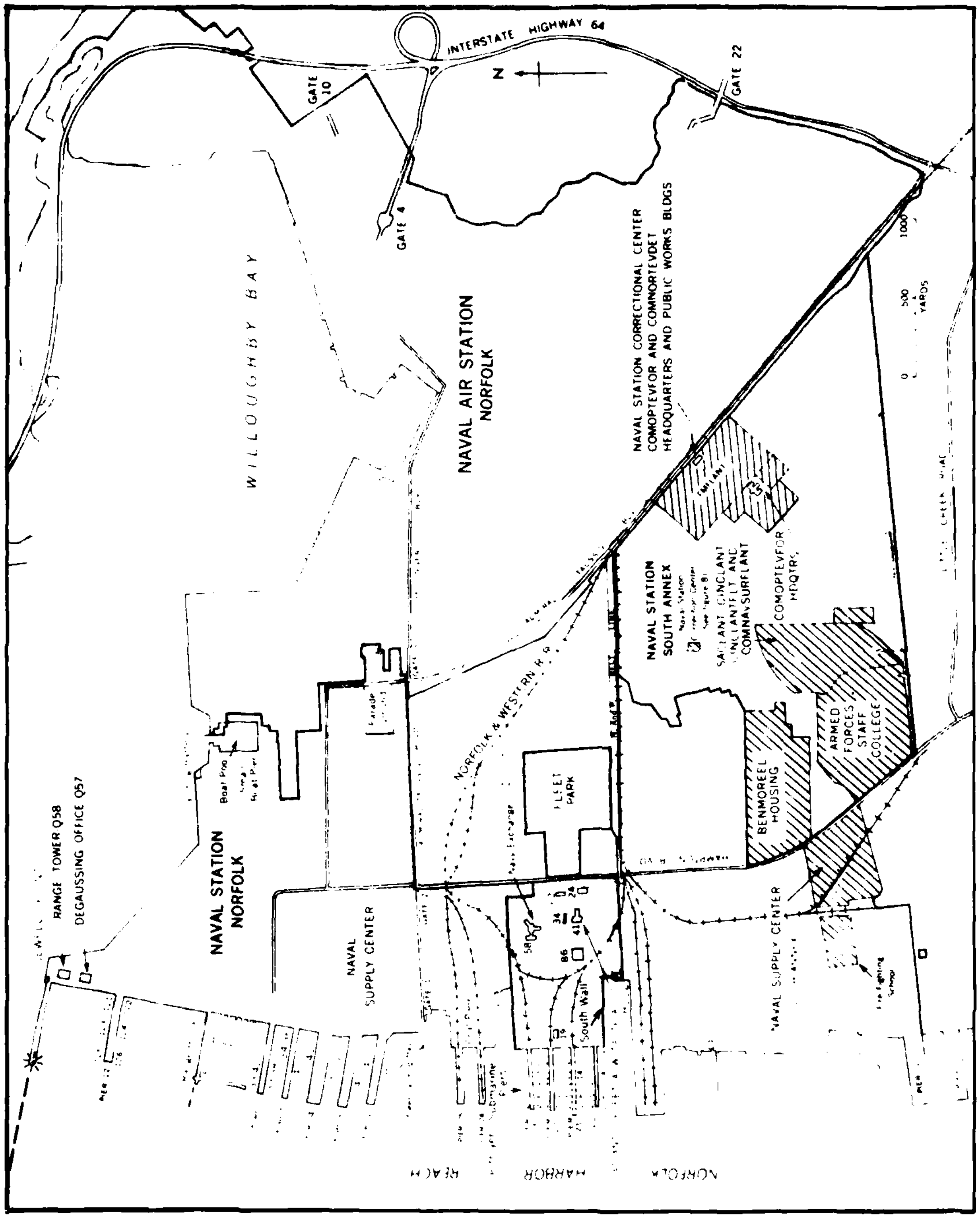


Figure II-2. Norfolk Naval Station showing locations of piers.

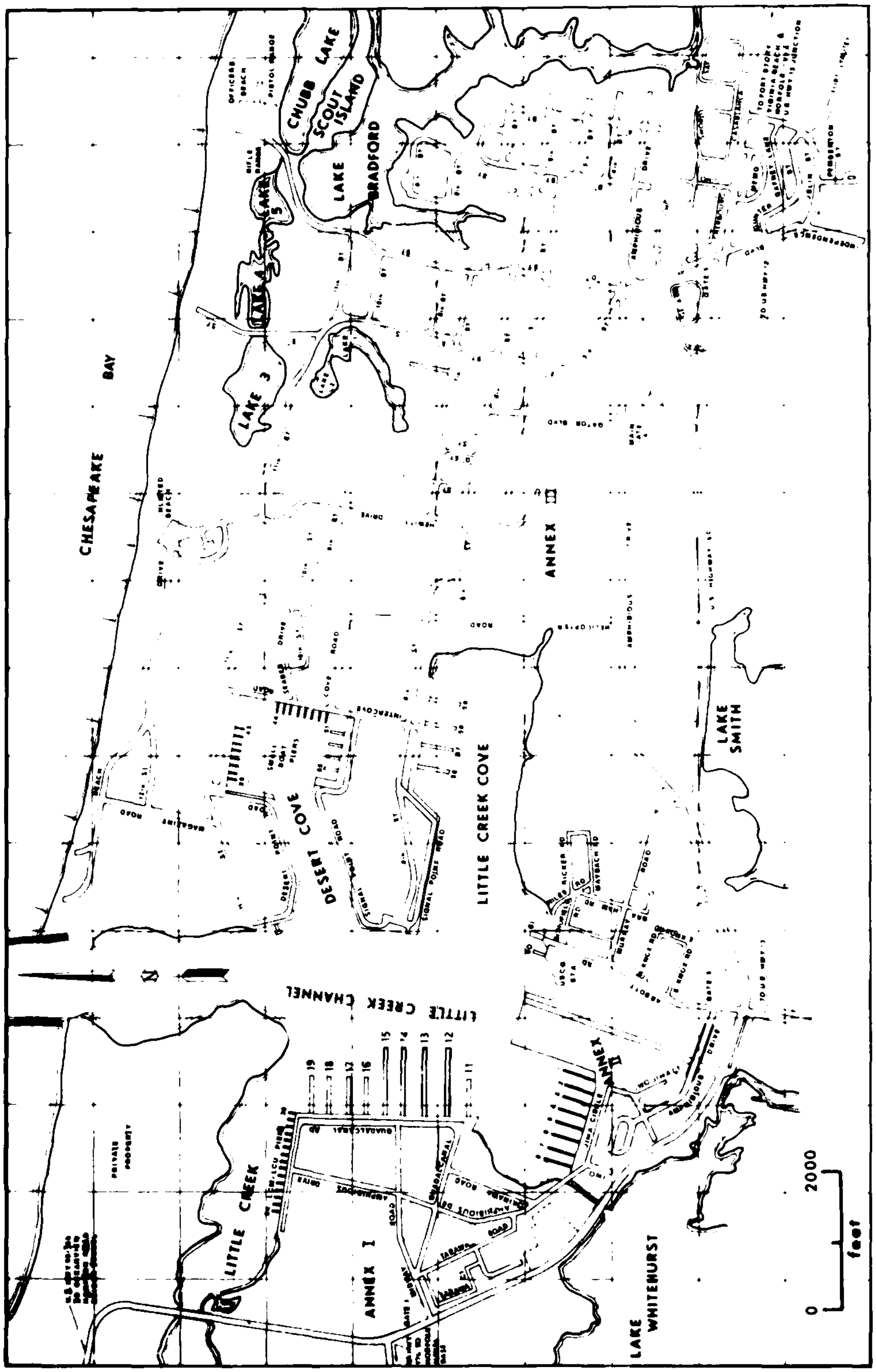


Figure II-3. Naval Amphibious Base, Little Creek, showing locations of piers.

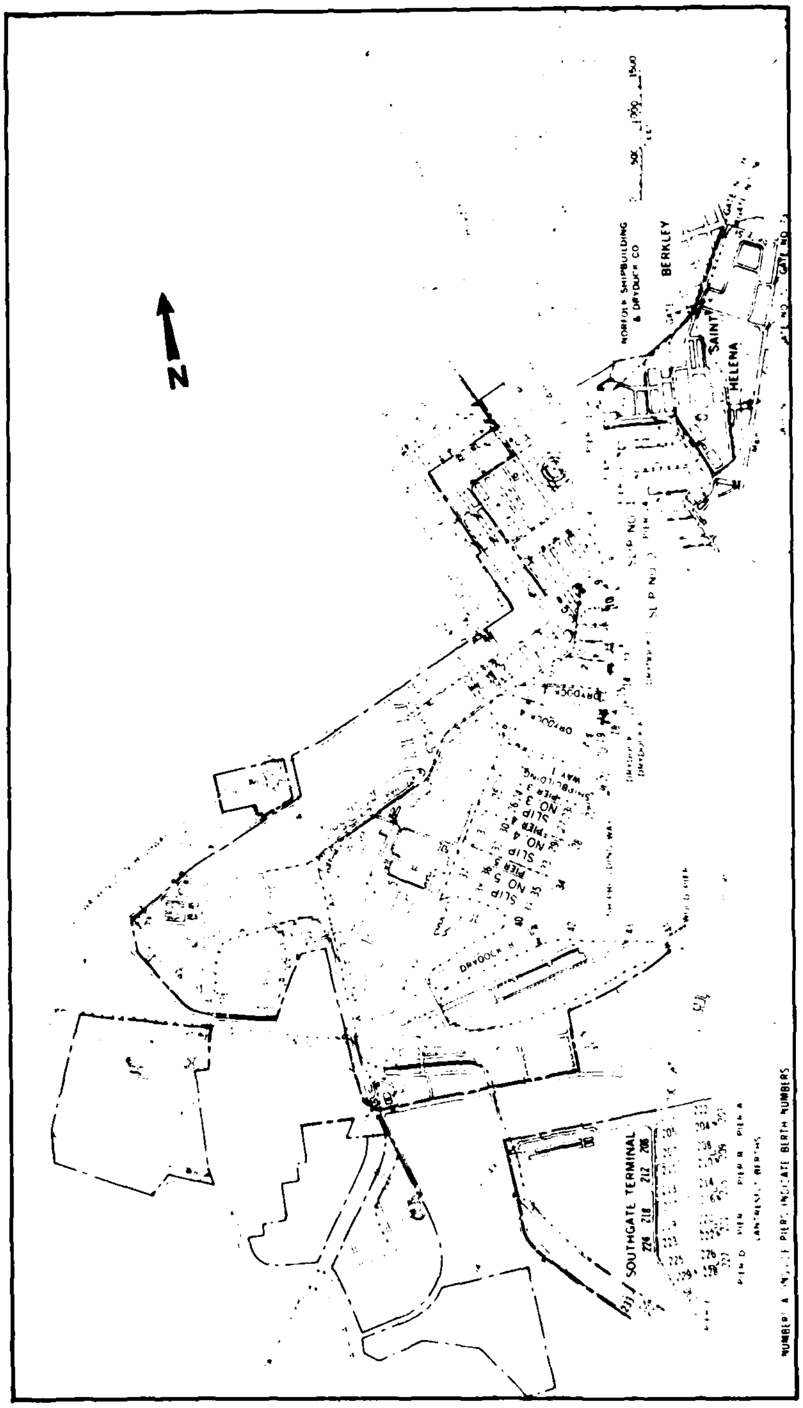


Figure II-4. Norfolk Naval Shipyard showing locations of piers and docks.

DMA Hydrographic/Topographic Center, Publication 940 Chapter 5, Fleet Guide to Hampton Roads.
Chart 12221 Chesapeake Bay Entrance
Chart 12253 Norfolk Harbor and Elizabeth River.

3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

3.1 TUG AVAILABILITY

Commanding Officers of vessels who may be required to shift berth, move to an anchorage or put to sea in the event of a tropical cyclone affecting the Norfolk area, should bear in mind that the services of the limited number of tugs will be at a premium before and after the passage of a tropical cyclone. Demand for tugs will be particularly high at certain stages of the tide and during normal working hours. Calls for towage assistance, especially for smaller vessels, should therefore be kept to a minimum and should be made only in case of real emergency as when life and ships are endangered.

3.2 HURRICANE ANCHORAGES

Hurricane anchorages have been designated in the central part of Chesapeake Bay. One set of hurricane anchorages for shallow and deep draft ships lies in the Naval Firing Range between Wolf Trap Light and Tangier Island (Figure II-5). An additional five berths, designated A through E and intended primarily for destroyer/submarine tenders and the senior officer from the Destroyer-Submarine Piers, are located about 3 n mi southward of the southernmost extremity of the above-mentioned anchorage areas.

Hurricane anchorage areas in the aerial gunnery range between Pt. Lookout and Cedar Pt. are for deep-draft ships, and are shown in Figure II-6. The diameter of all the berths is 2000 yds. The relevant charts are 12221, Chesapeake Bay Entrance; 12225, Chesapeake Bay-Wolf Trap to Smith Pt.; and 12230, Chesapeake Bay-Smith Pt. to Cove Pt.

Norfolk and Little Creek subarea SOPA (ADMIN) and COMNAVSURFLANT REP Norfolk make hurricane anchorage assignments for ships in their subareas which are capable of getting underway. Ships in the Norfolk subarea are assigned anchorages 0A through 7E; Little Creek subarea anchorages are 16A, 17A through 17E, F1 through F5, F7 through F19, G1 through G7, G9 and G10; and COMNAVSURFLANT REP Norfolk is assigned anchorages A through E, 8A through 15E and 16B through 16E for ships at the Destroyer-Submarine Piers. Hurricane anchorages are not assigned to submarines or to USCG ships unless specifically requested. Anchorage assignments are promulgated as early as possible with order and time interval of departure of ships for planning purposes. Sortie is executed on order of SOPA Hampton Roads area. Ships and afloat staffs should be familiar with COMNAVBASE INST 5400.1D (Manual of the SOPA (ADMIN) HAMPTON ROADS AREA) which contains complete instructions for hurricane measures in the Hampton Roads area. SOPA sets hurricane/tropical storm conditions for ships and initiates order movements to hurricane anchorages when anticipated winds indicate such action is prudent.

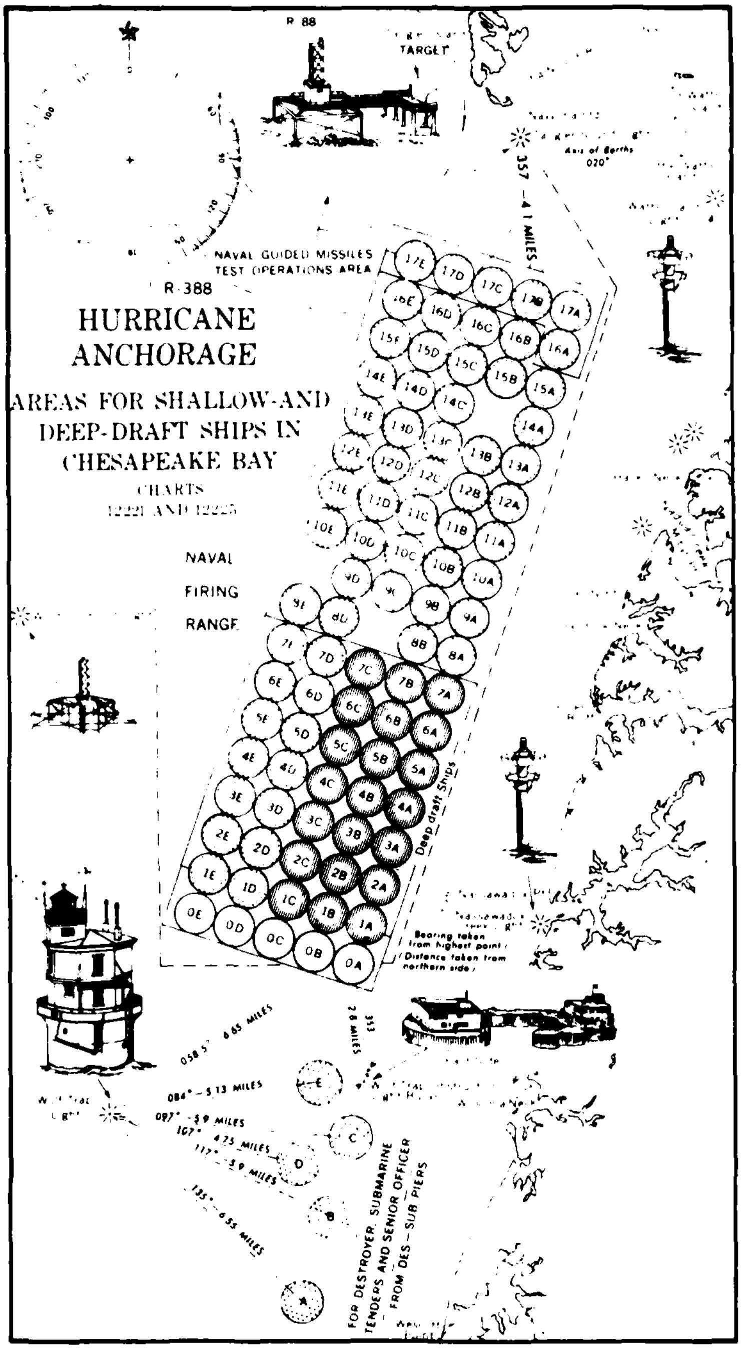


Figure II-5. Layout of anchorages for shallow draft ships located in the Naval Firing Range (from Fleet Guide to Hampton Roads).

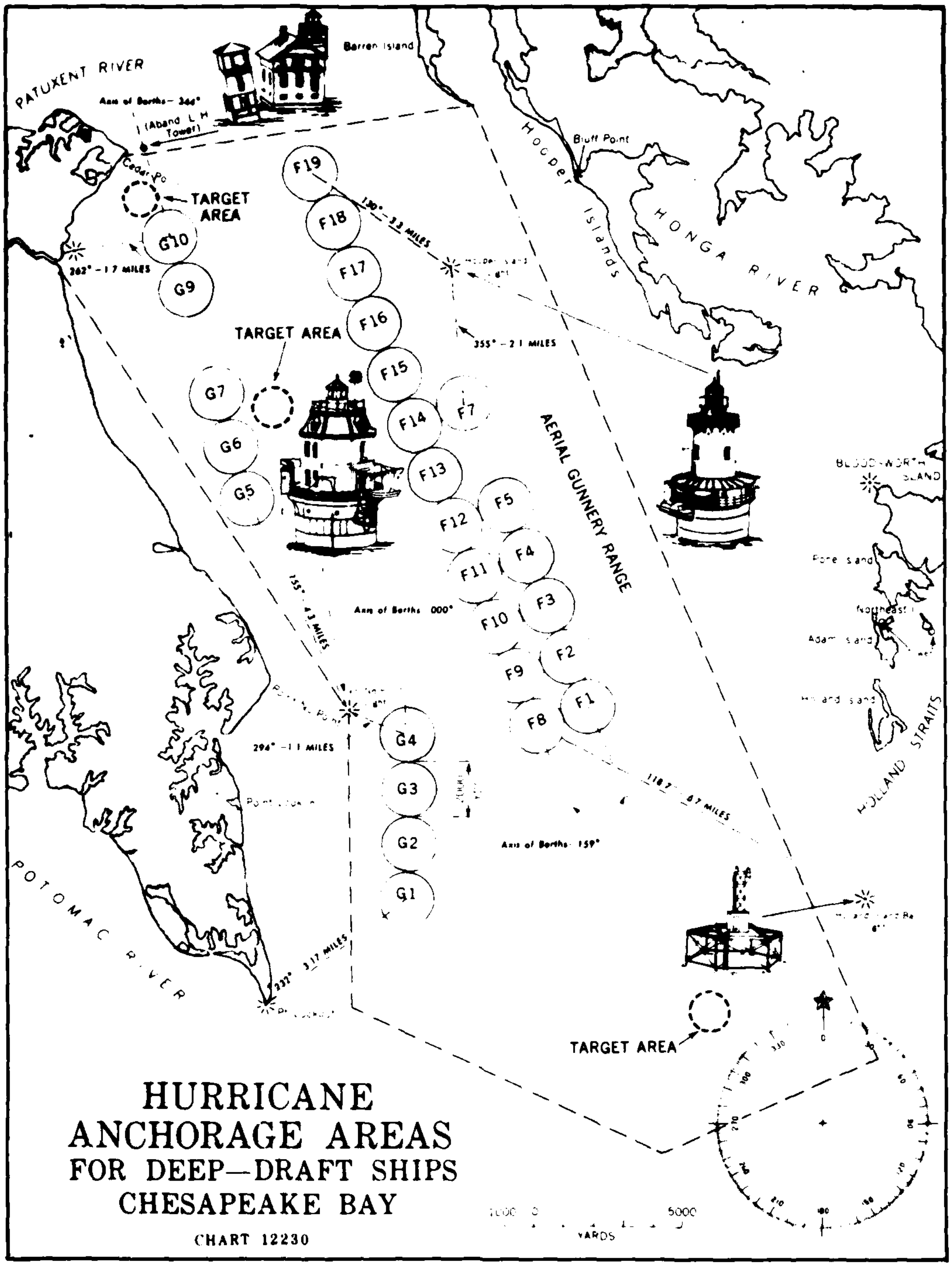


Figure II-6. Layout of anchorages for deep draft ships located in the Aerial Gunnery Range (from Fleet Guide to Hampton Roads).

4. TROPICAL CYCLONES AFFECTING NORFOLK

4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Norfolk is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Norfolk in some way, but a criterion had to be established for this study.

Although tropical cyclones have occurred in the North Atlantic during most of the year, the majority of those which threaten Norfolk occur from August to October. Figure II-7 depicts the monthly summary of tropical cyclone occurrences based on data for the 34 years from 1945-1978. Of the 54 tropical cyclones which threatened Norfolk in this 34-year period (less than two threats per year), 50 occurred in the period June to October with the peak threat in August and September.

Figure II-8 displays the above storms as a function of the compass octant from which they approached Norfolk. The open numbers indicate the number of cyclones which approached from that octant. The numbers in parentheses represent the same information, but as a percentage. It is evident from this figure that the majority of cyclones approach Norfolk from the south.

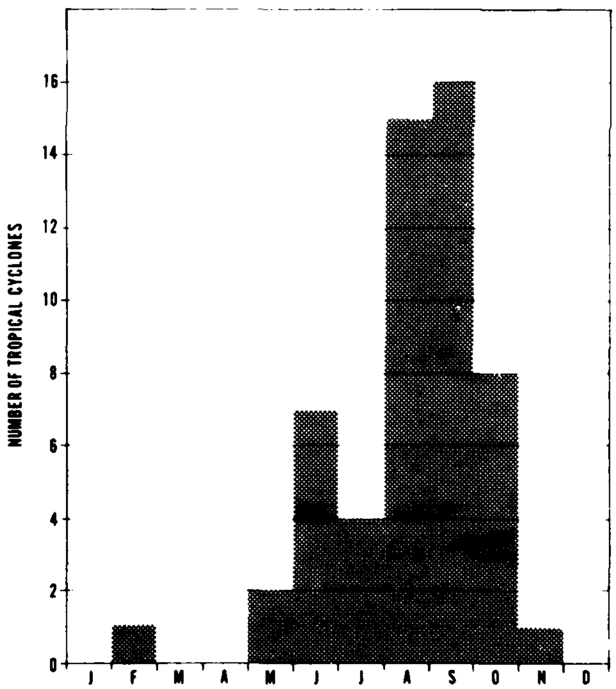


Figure II-7. Frequency distribution of tropical cyclones that passed within 180 n mi of Norfolk during the period 1945-1978.

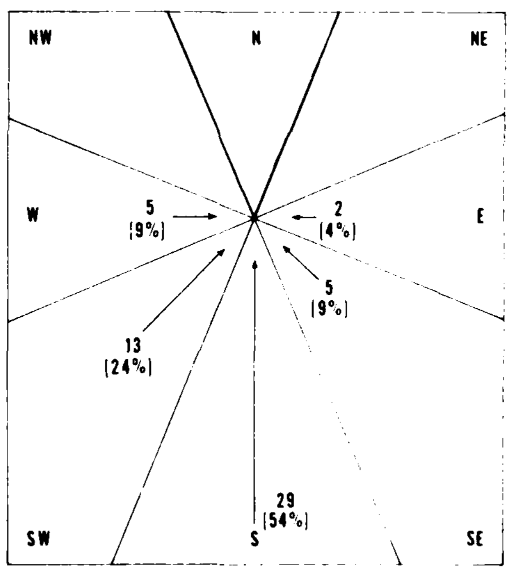


Figure II-8. Direction of approach of tropical cyclones that passed within 180 n mi of Norfolk during the period 1945-1978. Numerals are the number of tropical cyclones approaching from each octant, and percentages in () are percent of total sample of 54 storms that approached from each octant.

Approximately 1.6 tropical cyclones a year pose a threat to Norfolk. Since Norfolk lies at such a high latitude (37^{O}N) most of these cyclones are in the process of recurvature (i.e., they are recurving from a westerly track onto a northerly or northeasterly track). During this process, the tropical cyclones tend to accelerate their forward movement to an average speed of 16-18 kt at CPA for tropical cyclones approaching from the south and southwest. Those tropical cyclones which are still on a westerly or northwesterly track have an average forward speed of only 10-12 kt in this region.

A consequence of Norfolk being on the east coast is that tropical cyclones which pass to the west tend to have a longer land track than those which pass to the east, or those which approach from the southeast. As soon as a tropical cyclone passes over land, its energy supply is drastically reduced and there is a tendency for the cyclone to weaken. Thus the direction of the threat and the direction of CPA is of utmost importance in the Norfolk situation.

Figures II-9 to II-13 are a statistical summary of threat probability based on tropical cyclone tracks for the years 1945 to 1978.[1] The data are presented monthly during the main part of the hurricane season, August through October (Figures II-9 to II-11); Figure II-12 is for the remainder of the year, November through July, and Figure II-13 is for the whole year. The solid lines represent the "percent threat" for any storm location. The dashed lines represent approximate approach times to Norfolk based on the climatological approach speed for the particular area and direction of movement. For example, in Figure II-9, a tropical cyclone located at 25^{O}N and 66^{O}W has approximately a 40% probability of passing within 180 n mi of Norfolk and will reach Norfolk in 3-4 days if the speed remains close to the climatological normal. It will be noted from Figures II-9 to II-11 that at the beginning of the main hurricane season in August the major threat axis is a curve from just east of the Lesser Antilles passing north of the Bahamas and then recurving up to the North Carolina coast. As the season progresses, the threat axis rotates clockwise so that by October, it follows a line from the Yucatan Channel, across the Gulf of Mexico and Florida to approach Norfolk from the southwest. During the remaining months of the year, November through July (the majority of tropical cyclones within this period being in June and July), Figure II-12 indicates a double threat axis which combines the two axes mentioned above. For the year as a whole, Figure II-13 inevitably embodies both the southeasterly and southwesterly threat axes.

4.2 WIND AND TOPOGRAPHICAL EFFECTS

In the 34-year period from 1945-1978, a total of 54 tropical cyclones approached within 180 n mi of Norfolk, an average of 1.6 per year. A tabulation of the intensity of these tropical cyclones at their CPA to Norfolk is presented in Table II-1. The data is also separated according to whether the tropical cylone passed to the east or west of Norfolk, and consequently whether it gave generally northerly or southerly winds. It can be seen from Table II-1 that the vast majority of tropical cyclones pass to the east to give northerly winds. In fact, no tropical cyclone that was still of hurricane intensity ($\geq$64 kt) passed

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[1]Track information was obtained from Neumann et al, 1978.

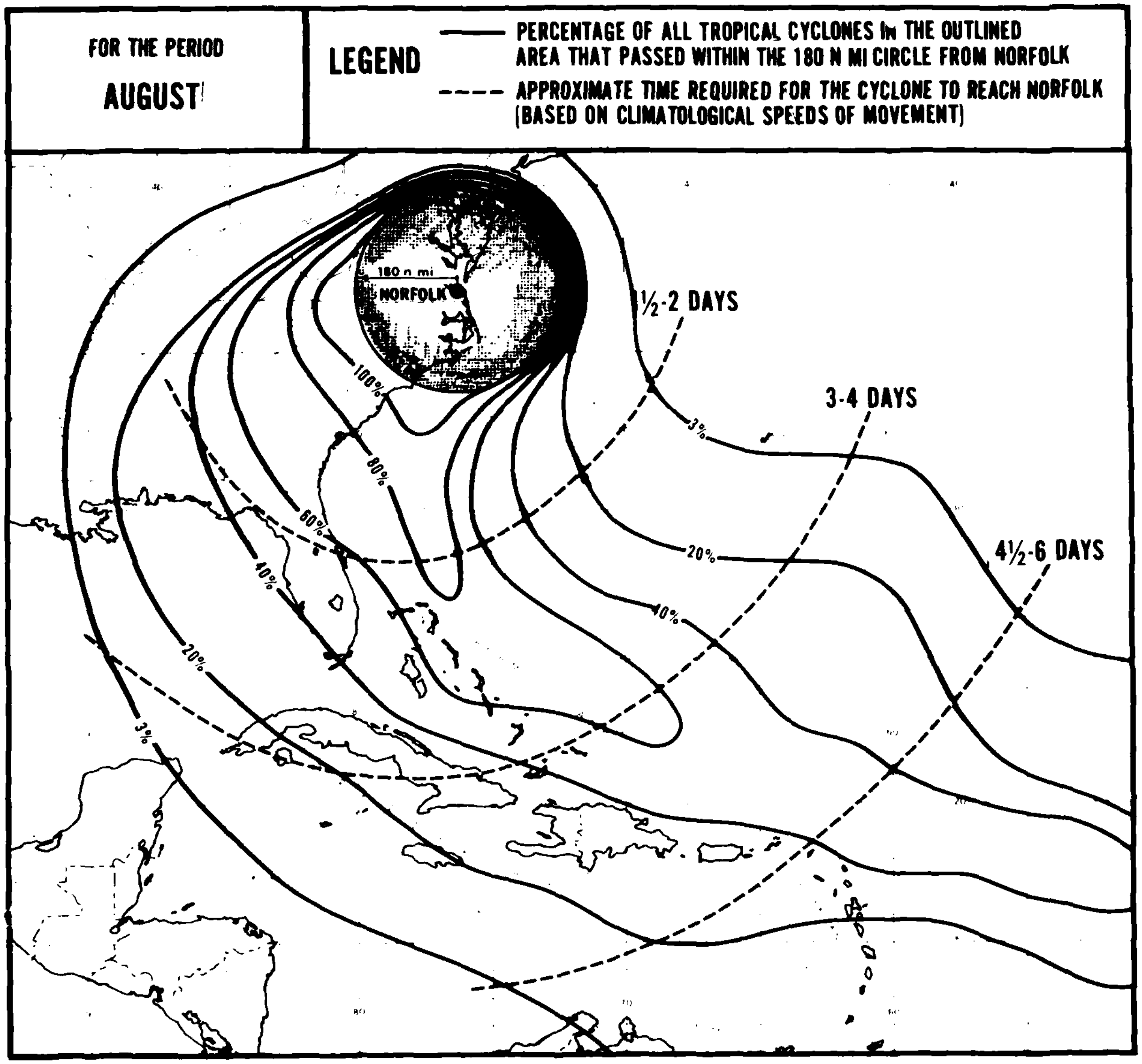

Figure II-9. Probability that a tropical cyclone will pass within 180 n mi of Norfolk during the month of August (based on data from 1945-1978).

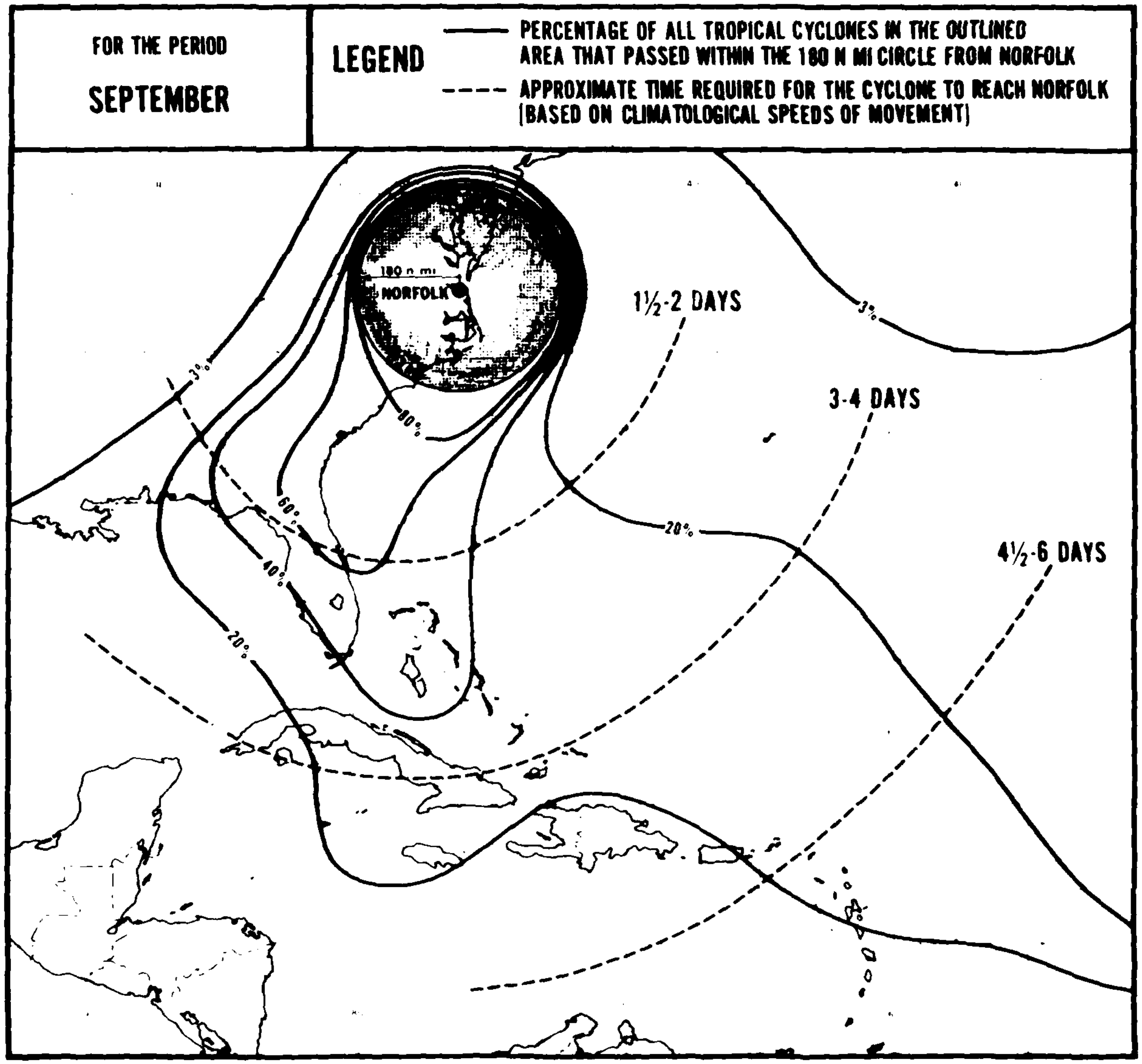

Figure II-10. Probability that a tropical cyclone will pass within 180 n mi of Norfolk during the month of September (based on data from 1945-1978).

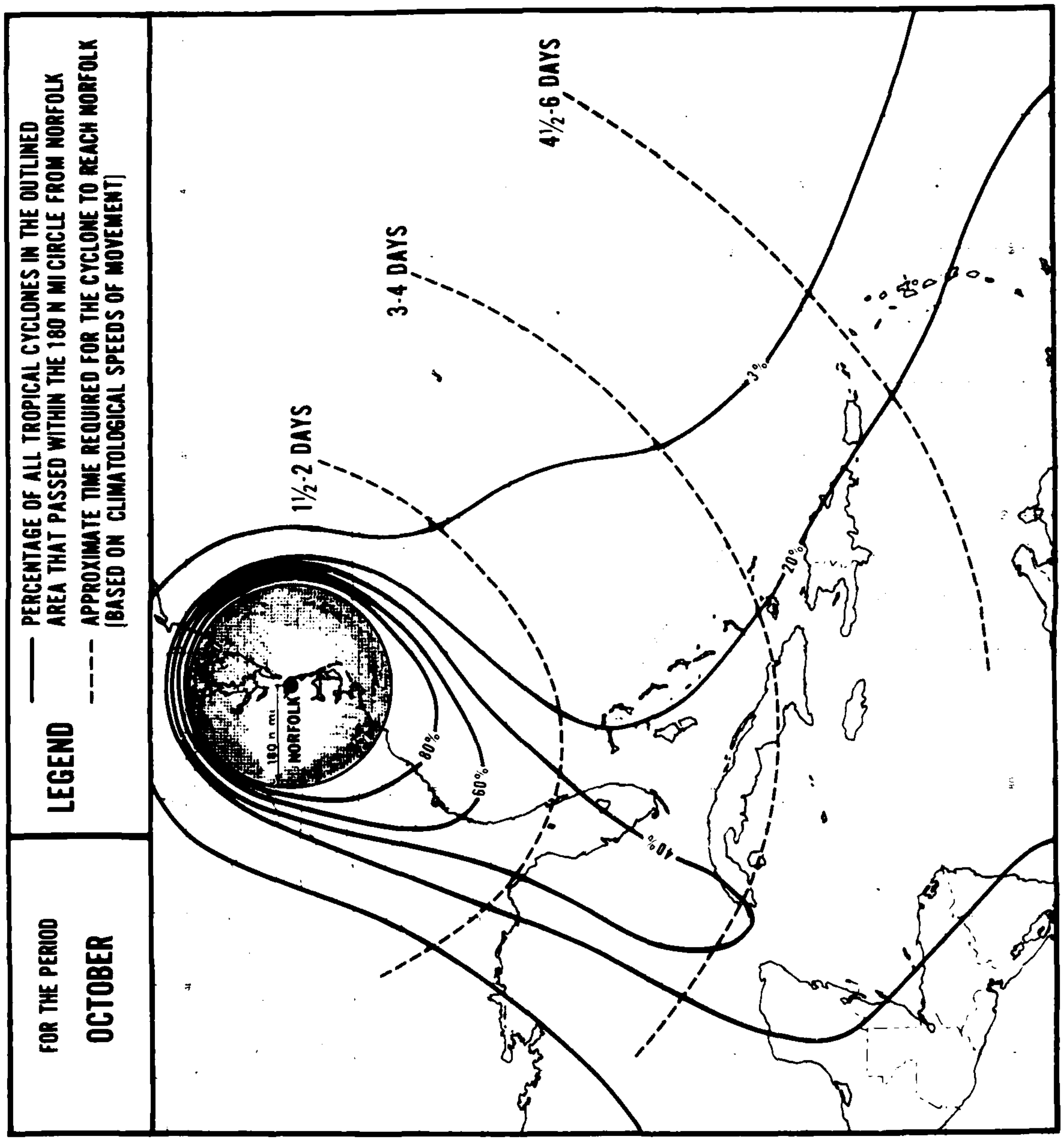

Figure II-11. Probability that a tropical cyclone will pass within 180 n mi of Norfolk during the month of October (based on data from 1945-1978).

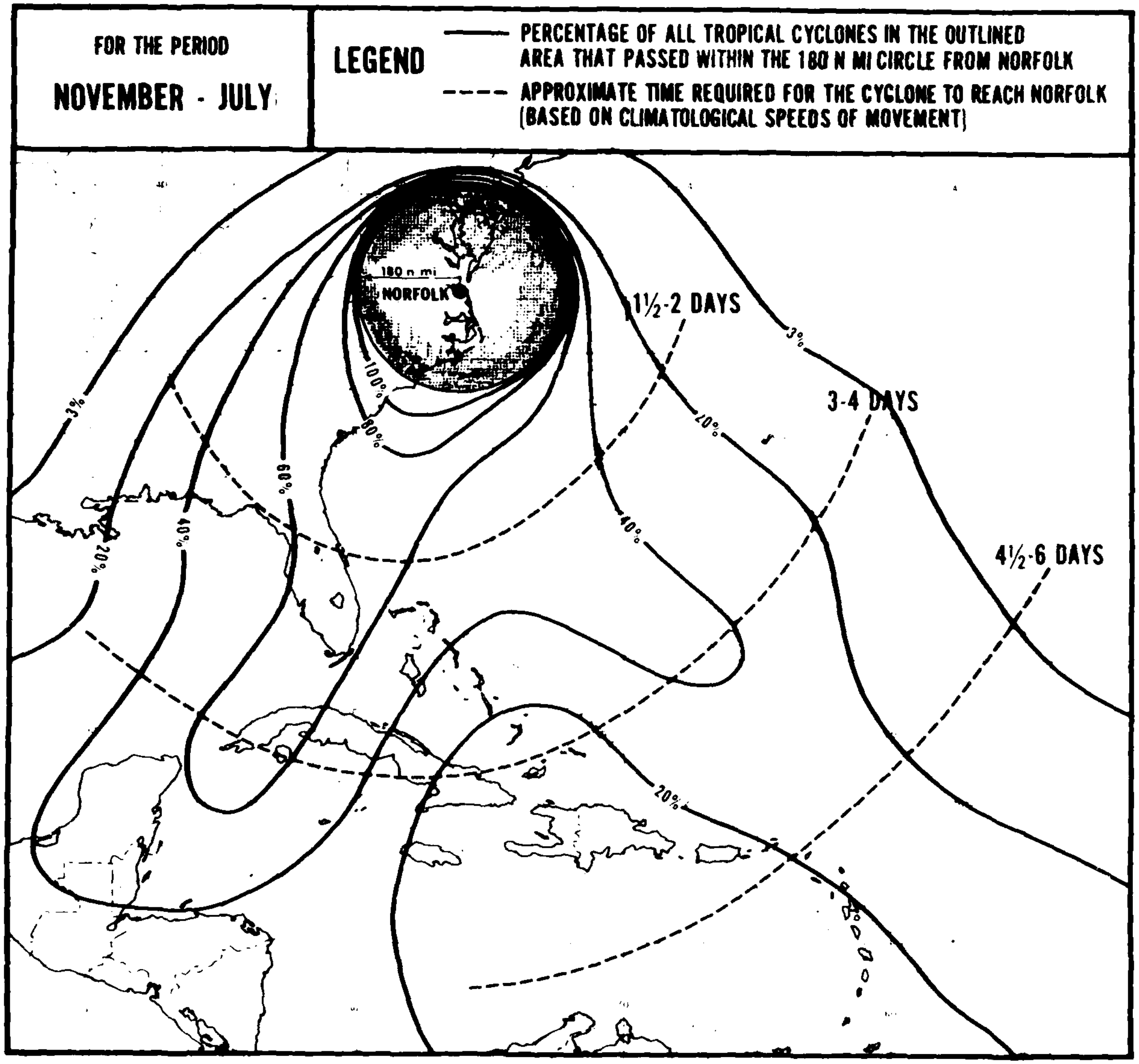

Figure II-12. Probability that a tropical cyclone will pass within 180 n mi of Norfolk during the months of November-July (based on data from 1945-1978).

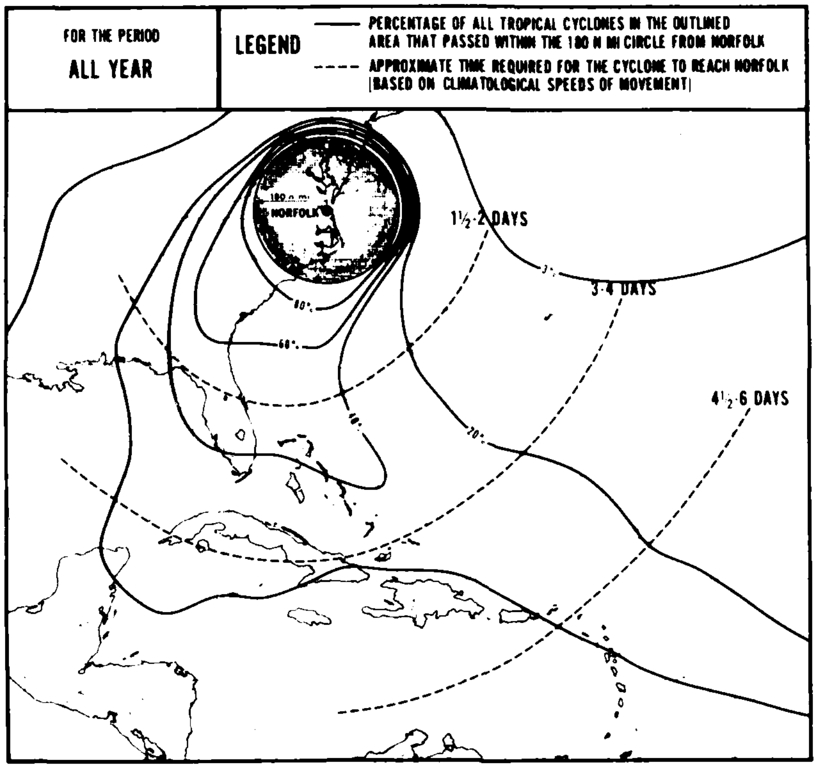

Figure II-13. Annual probability that a tropical cyclone will pass within 180 n mi of Norfolk (based on data from 1945-1978).

to the west.[2] The reason for this of course is that the cyclones which pass to the east tend to have had a longer and more recent sea track and therefore have tended to maintain their intensity. Those tropical cyclones which pass to the west of Norfolk tend to have had a long land track and therefore are usually weakening.

Table II-1. Classification of the 54 tropical cyclones which threatened Norfolk between 1945 and 1978 by intensity at closest point of approach (CPA) and whether they passed to the east or west.

	Hurricane	Tropical Storm	Tropical Depression*	Extratropical Stage	Total
East	17	12	6	8	43
West	0	6	1	2	9

*Two dissipating cyclones with tropical depression intensity approached from due west and are not included. One passed to the north, the other to the south.

[2] Note that extratropical Storm Hazel in 1954 passed to the west of Norfolk and caused sustained winds of 50 kt with gusts to 85 kt at NAS Norfolk.

According to hourly synoptic reports, out of the 54 threat tropical cyclones, 32 produced winds of 22 kt or stronger at NAS Norfolk. Out of these 32, 11 produced winds of 34 kt or stronger. The strongest wind at NAS Norfolk due to tropical cyclones during the period 1945 to 1978, according to hourly synoptic reports, was 50 kt in 1954 associated with extratropical storm Hazel. Associated peak gusts at NAS Norfolk for this period have been used to estimate the maximum one-minute sustained winds via the statistical relationship developed by Durst (1960) for wind spectra at level unobstructed land sites. This reveals three storms during the same period (1945 to 1978), contributed to maximum sustained winds of 50 kt or above (Barbara, 1953 - 50 kt; Hazel, 1954 - 62 kt; and Donna, 1960 - 50 kt).

Earlier records of hurricane effects at Norfolk (Ritter, 1980) suggest a similar frequency of operationally significant winds. In the period 1900 to 1944, one and perhaps two significant occasions (both in 1933), saw sustained hurricane force winds at the Naval Station and on three other occasions sustained winds of 50 kt or above were experienced there. Nineteenth century records do not enable reliable estimates of wind speed at the Naval Station to be made, but provide a useful indicator to wind strengths at the entrance to Chesapeake Bay. On 16 occasions in the 100 year period from 1871, hurricane force winds have been recorded at Cape Henry (i.e., once in every 6 years). By contrast, the frequency of hurricane force winds at the Naval Station is approximately once every 30 years, but the frequency of sustained winds of 50 kt or more is once every 10 years.

Thus tropical cyclones of full hurricane intensity are relatively rare at Norfolk as a result of shelter from meteorological rather than topographical factors. Vigorous storms tend to be well to the east near the Gulf Stream, whilst storms passing close or to the west of Norfolk are likely to be weakened by their relatively long land track. The two most destructive cyclones at Norfolk this century possessed unusual features. Hurricane No. 8 in August 1933 approached Norfolk in a northwesterly direction and by this unusual direction of movement maintained its intensity by minimizing its land track. Hazel in 1954, however, was passing well to the west having become extratropical at its CPA, whereupon it was invigorated by encountering a strong cold outbreak from the northwest.

Figure II-14 depicts the track segments of tropical cyclones that occurred between 1945 and 1978 which resulted in gale force winds ($\geq$34 kt) at NAS Norfolk. It is apparent from this figure that the majority of tropical cyclones contributing to gale force winds are to the south and east of Norfolk and approach from the south or southwest. This major threat direction is also represented by the "percent threat" lines of Figures II-9 through II-13 and in Figure II-8 by the octant approach arrows. Eight of these eleven cases occurred in August and September.

Figure II-15 gives the positions of tropical cyclone centers when strong winds ($\geq$22 kt) and gale force winds ($\geq$34 kt) were recorded at NAS Norfolk for the years 1945 to 1978. It is apparent from this diagram that strong winds have occurred with the tropical cyclone center nearly 500 n mi away, and gale force winds have occurred with the center up to 350 n mi away. It is also noteworthy that the majority of strong wind cases have occurred with the tropical cyclone center to the northeast, east or south, consistent with the data in Table II-1.

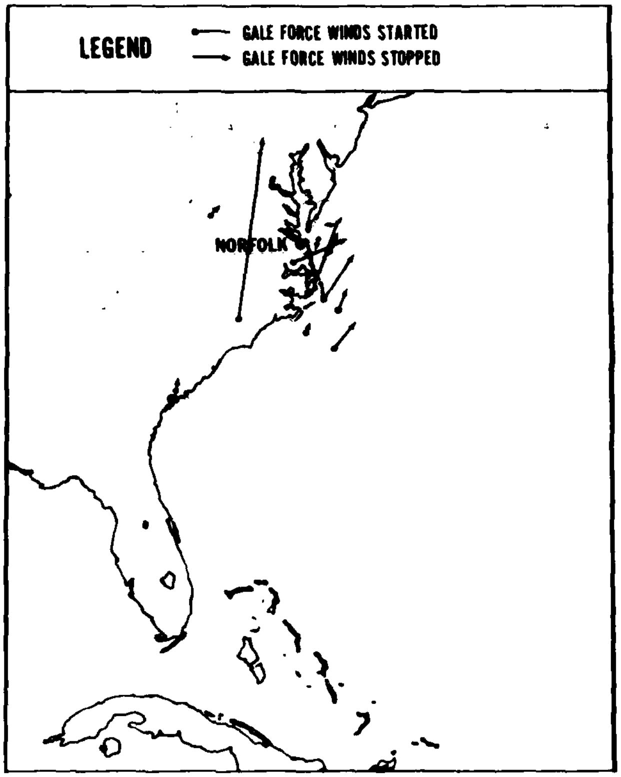

Figure II-14. Positions of 11 tropical cyclone centers when 34 kt winds first and last occurred at NAS Norfolk (based on hourly wind data for the years 1945-78).

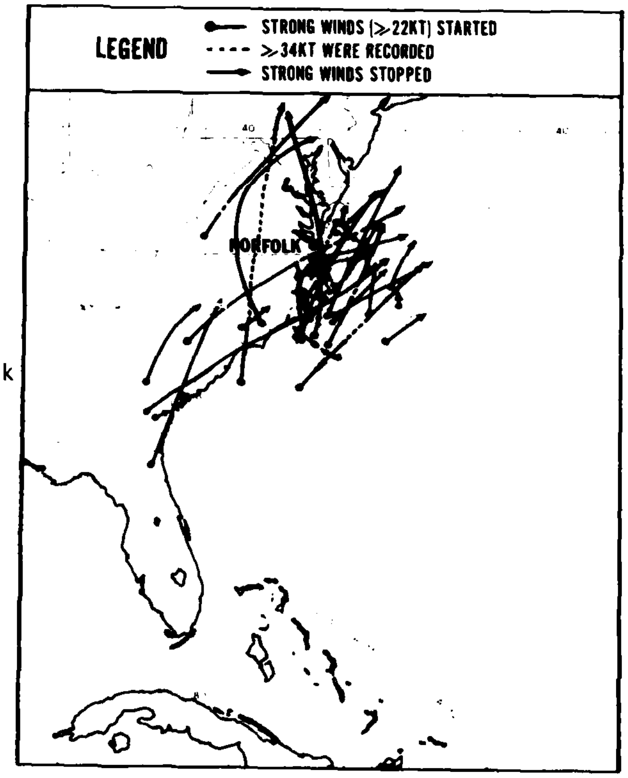

Figure II-15. Positions of 32 tropical cyclone centers when 22 kt winds first and last occurred at NAS Norfolk (based on hourly wind data for the years 1945-78).

Figure II-16 shows the complete tracks of the tropical cyclones which gave gale force or greater winds at NAS Norfolk between 1945 and 1978.

Although the land in the Norfolk area is very low and featureless (the average altitude in the area is only thirteen feet above mean high water), there is some sheltering from certain directions caused by the usual surface friction with the land. Norfolk Naval Station is particularly susceptible to winds from southwest clockwise to north, and least susceptible to winds from the southeast. Naval Amphibious Base Little Creek is most susceptible to northerly winds and least susceptible to southerly winds. Norfolk Naval Shipyard has some sheltering from all directions. However, any sheltering from the wind that does occur in any of these locations is minimal and is likely to increase the gustiness. The virtue of the Norfolk area is that whereas little shelter is offered by topographical features, the particular combination of its latitude, and orientation of the coastline provides protection from the more vigorous cyclones.

4.3 WAVE ACTION

4.3.1 Norfolk Naval Station

Norfolk Naval Station is not susceptible to waves produced by winds with an easterly component. It is also totally protected from ocean swells or even swells produced by the long fetch in Chesapeake Bay. For winds with a westerly component, a hazardous sea soon affects the piers. When the wind reaches 18 kt a sea dangerous to small boating already exists. A rough calculation using forecasting curves from the U.S. Army Coastal Engineering Center Shore *Protection Manual (1973)*, shows that westerly winds of 30 kt will produce 3 ft waves, 50 kt will produce 4.5 ft, and 70 kt will produce 6 ft. At the more northerly piers, 2 through 12, conditions will be slightly worse due to the deeper water just off shore. If the wind direction is such that it blows directly along the James River, then a further 0.5 ft can be added to the calculated heights. For northerly winds, conditions are much better due to the considerably reduced fetch. It therefore appears that the worst conditions for sea state at Norfolk Naval Station would arise after the close passage of the eye of the cyclone with the center lying in a direction between north and northeast. Normally, this condition will arise for tropical cyclones moving northwards up the east coast, after the center has passed Cape Henry. For a tropical cyclone passing to the west to give such conditions, it would have to pass very close, and then such conditions would probably only exist for a few hours immediately after passage of the eye.

4.3.2 Naval Amphibious Base, Little Creek

The Little Creek Naval Amphibious Base is only susceptible to northerly seas generated in Chesapeake Bay. Since the southern end of the bay becomes shallow, any large waves generated in the deeper central portion will tend to break offshore. It is reported by local personnel that Chesapeake Bay can only support waves up to 8-10 ft. Waves of 5-6 ft have been experienced just outside Little Creek Harbor in winds of 40-50 kt. Inside the harbor, the waves are attenuated rapidly and only affect piers directly in line with the entrance or

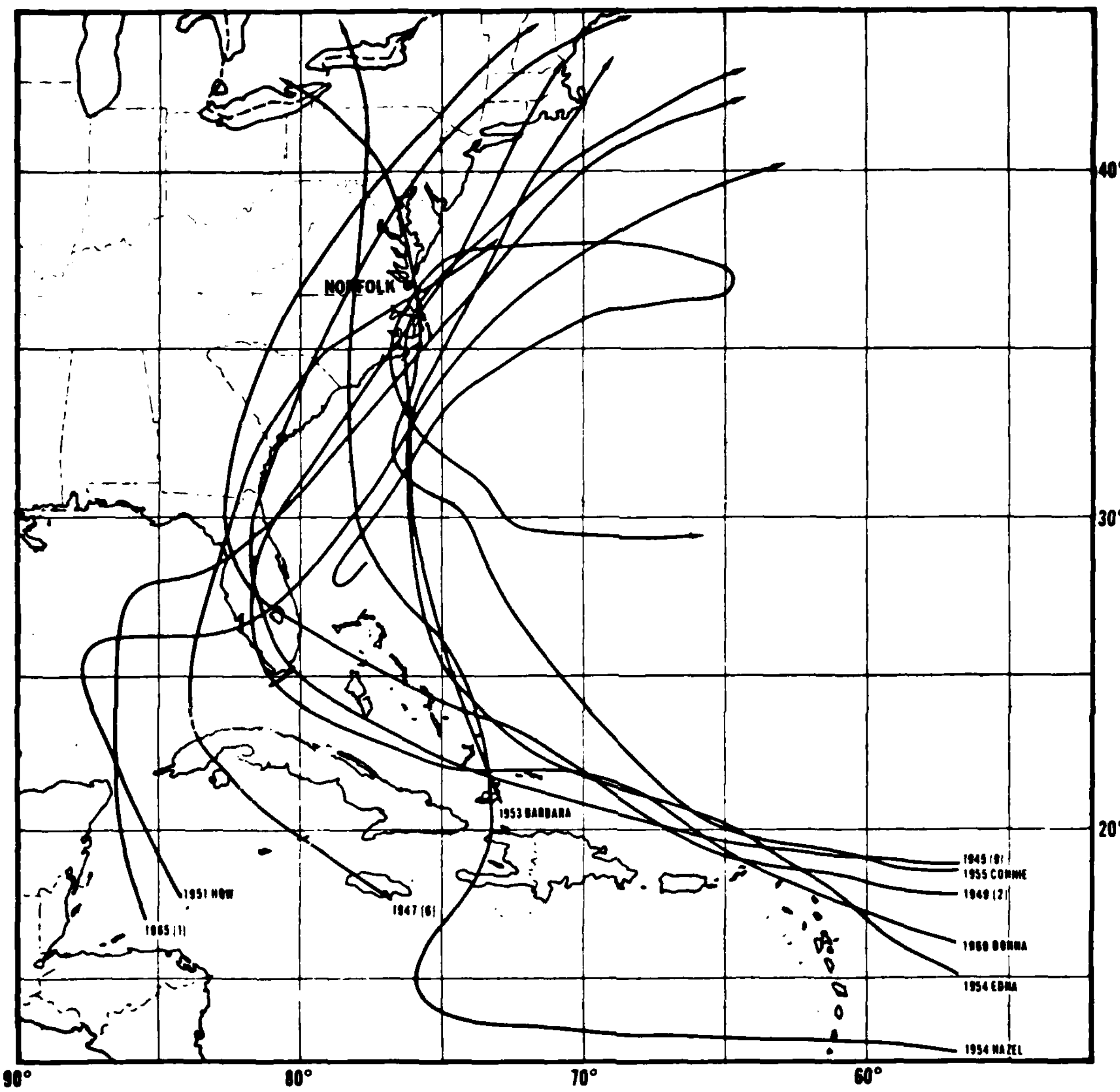

Figure II-16. Tracks of 11 tropical cyclones that produced winds of 34 kt or greater at NAS Norfolk (based on data from the years 1945-78).

ships which protrude past the ends of the piers. To avoid this problem, piers 12-15 have been extended by 200 ft to a new total length of 620 ft to accommodate the longer vessels.

Calculations show that Chesapeake Bay could support 8-10 ft waves in a 50 kt northerly wind in its deeper central portion. The amplitude of such waves would indeed be reduced by the shallows at the southern end of the bay. In a 90-100 kt wind, it is unlikely that waves greater than 12 ft could be supported at the southern end of the bay due to its shallow nature, but conditions in the breaking waves would be treacherous. Little Creek therefore is relatively well protected from wave action, and real problems would occur during the close passage of a hurricane to the east.

4.3.3 Norfolk Naval Shipyard

Norfolk Naval Shipyard is so situated that it is not susceptible to any significant waves from any direction.

4.3.4 The Hurricane Anchorages

The hurricane anchorages described in Section 3.2 are situated in the central portion of Chesapeake Bay. The northernmost anchorages in the Aerial Gunnery Range are for deep draft ships. The water depth there is generally between 30 and 60 ft (9.1 and 18.3 meters). These anchorages are well protected from the build-up of significant seas except when the wind is blowing directly along the length of the bay, i.e., for north-northwest or south-southeast winds. With a NNW wind, the fully arisen sea is calculated to be 12-14 ft in 70-90 kt winds. Similar conditions are likely in a SSE wind, but it is unlikely that the anchorages would be used in such conditions as it is relatively easy to evade at sea. For the passage of a tropical cyclone to the east, passing northwards up the east coast, the winds are most likely to be NNW for a considerable time due to the tendency for the winds to be funneled.

The southernmost anchorages in the Naval Firing Range are for the shallower draft ships. The water depth here is generally between 20 and 40 ft (6.1 and 12.2 m). These anchorages are slightly more exposed than the deep draft anchorages, but the shallower water depths in the vicinity precludes the build-up of such high seas. The calculated maximum wave height is 8-10 kt for 50 kt northerly winds and 10-12 ft for 70-90 kt winds. Similar conditions are expected in southerly winds, but the anchorages are again unlikely to be used when such conditions are expected due to the relative ease of evasion. For other wind directions, there is sufficient fetch for significant seas to build, especially in the northernmost anchorages of this block. In a west or northwest wind, at 50 kt, 6 ft waves can be expected and at 90 kt, 9 ft waves. Such a wind direction is unlikely to prevail for any length of time. For northeast through southeast wInds, conditions will be considerably better than above.

4.4 STORM SURGE AND TIDES

Storm surge can be defined as the difference between observed water level and expected water level at a given location during storm conditions. Storm surge varies considerably in this area even over quite short distances due to

the highly variable bathymetry and shoreline shape. Other factors which affect the water level are; direction, velocity and persistence of the wind; the atmospheric pressure; water transport by waves and swell; and rainfall. The actual surge to be expected, therefore, will be difficult to forecast. The National Weather Service has developed computer prediction models, and will issue storm surge forecasts as appropriate. The approximate surge height to be expected can be estimated from past experience. The highest surge that Norfolk has ever experienced at the Sewells Point gage was 6.2 ft in August 1933. Since this surge happened at high water, the actual tide height was 9.7 ft.[3] Such a surge would not only be a disaster for many ships, but for the low lying land areas it would be a catastrophe. The maximum predicted surge using a computer model of the worst possible situation is approximately 11.5 ft at Cape Henry. This would result from a hurricane with maximum winds of 120 kt moving due west towards Norfolk and making landfall some 15 miles south of Cape Henry. Such a hurricane would cause northeasterly winds for a considerable time, especially if it was slow moving. The whole area is most prone to high surges caused by northeasterlies with extra caution being necessary during periods of coincidence of exceptionally high seasonal tides and storm surge. For north winds and east winds, a storm surge will still occur but with less amplitude. For other wind directions, southeast through southwest to northwest, no surge is likely. However, winds from the southerly quadrant tend to cause a negative surge, and this can result in lower low tides than predicted.

Tides in the vicinity of Norfolk are not normally a problem. The mean tidal range in Hampton Roads is 2.5 ft., and the current velocity is 1.1 kt. In the Elizabeth River, the current velocity is 0.6 kt. These values are considerably influenced by the wind, and under surge conditions, may well exceed the tabulated values by several knots. At Little Creek, the normal current flow is 0.5 to 1.5 kt. This is reported to increase to 6 kt under 40-50 kt northerly winds with a flood tide, but is only of real concern to ships entering the harbor. In hurricane conditions, all these current velocities will be increased still further and will be a considerable hazard to ship movement.

5. THE DECISION TO EVADE OR REMAIN IN PORT

Specific instructions to ships for dealing with severe weather are laid down in COMNAVBASENORVA INST 5400.1D Section 3141. A definition of Tropical Storm/Hurricane Conditions I through IV is also given, together with the status of preparedness and action required to achieve each condition of readiness.

5.1 EVASION RATIONALE

The most important aspect of any decision concerning heavy weather is an early appraisal of the threat posed by an individual tropical cyclone. Tropical cyclones which cross Florida or the Bahama Islands and finally recurve northwards have in the past had a relatively high probability (40-60% for the whole

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[3] It should be noted that the maximum sustained wind observed in Norfolk was approximately 60 kt from the northeast.

year) of passing within 180 n mi of Norfolk. Any decision to sortie from Norfolk must be made early in order to gain maneuvering room in the open ocean, especially since large swells are likely to be generated that can severely reduce a ship's speed of advance even though the storm may well be far to the south.

An unfortunate consequence of an early decision is of course that the tropical cyclone forecast errors will be greater, both for the center position and for the intensity. The tendency therefore will be to delay any evasion decision until it is too late in order to obtain more accurate updated information. This is the dichotomy that the decision maker must face, and only worsened by the additional economic constraints of fuel conservation.

5.2 REMAINING IN ALONGSIDE BERTHS

Remaining in port when the means to evade a storm is available is a decision contrary to most of the traditional rules of seamanship. However, the final decision will depend on many factors, including the forecast wind intensity at the port and the track of the storm. Characteristics of the individual harbor in the forecast wind conditions must also be taken into account for each individual ship. The following should be considered.

5.2.1 Norfolk Naval Station

(a) Norfolk Naval Station is not a haven for carriers. When sustained winds of 50 kt or greater are expected, carriers should sortie at the earliest opportunity and evade at sea.

(b) Large ships, especially those with large sail areas, should also go to anchor or evade at sea when 50 kt or greater sustained winds are expected.

(c) Smaller ships should sortie on the rare occasions when hurricane winds are expected ($\geq$64 kt).

(d) Small boats and service craft should evacuate to the Norfolk Naval Shipyard when gale force winds are expected, if they cannot be removed from the water.

(e) Those ships seeking shelter in the harbor in any conditions should obtain a berth on the windward side of the pier when possible. The ships should increase the number of lines, and should keep a close watch on the lines in case of storm surge. The maximum storm surge will not necessarily occur at the same time as the strongest winds.

(f) Wave conditions will be far worse for any particular wind strength if the wind has a westerly component rather than an easterly component.

(g) Storm surge will be at its worst with high seasonal tides and north-easterly winds.

5.2.2 Naval Amphibious Base, Little Creek

(a) The controlling depth is only 18 ft (5.5 m) and it will normally only be used by amphibious ships.

(b) The harbor provides good protection from sea and swell, but not necessarily from wind and storm surge. Northerly winds are considered to produce the greatest hazard in terms of both wind strength and surge height.

(c) Ships will normally sortie only if a sustained wind is forecast that will make the berths untenable. This will vary for each ship, but is expected to be over 60 kt (i.e., a rare occurrence).

(d) The best berths will be the windward sides of piers 12-15 which have been elongated to 620 ft. However, piers 11 and 16-19 are good for ships that do not protrude past the 420 ft length.

(e) Small boats and service craft should be moved from the water or moved to Desert Cove.

5.2.3 Norfolk Naval Shipyard

(a) Most ships will not be in a position to sortie and should be secured as well as possible.

(b) There will be a great demand for berths due to the shipyard's good small boat haven qualities. Requests and movements should be made early in order to avoid last minute confusion.

(c) Any large storm surge will cause an enormous problem, and a watch should be kept at all times to avoid boats breaking their mooring lines and becoming a problem for other vessels.

5.3 ANCHORING IN CHESAPEAKE BAY

Use of the hurricane anchorages in Chesapeake Bay will normally be confined to ships that decide to sortie from the Naval Station, Little Creek or the Shipyard and are unable to evade at sea easily. They may also be used when the harbors are expected to become marginally unsafe, but when evasion at sea would be impracticable or uneconomic. In either case, the following factors should be taken into account.

(a) The mud and sand bottom is considered good holding ground.

(b) Maximum wave heights will be between 10 and 14 ft for northerly winds of hurricane strength, and for winds not along the axis of the bay, will be considerably less.

(c) There is a possibility of ships dragging anchor and becoming a hazard to other ships at anchor unable to take avoiding action. A second anchor should be ready for dropping at any time, or should be dropped anyway to reduce yawing.

(d) There is a high probability that some of the numerous small vessels and barges seeking shelter in the upper part of Chesapeake Bay will be improperly secured and will come adrift. These drifting hulks will be a deadly threat to any ships anchored in their path.

(e) The bottom depths are convenient for anchoring, and should provide adequate underkeel clearance even in the highest seas possible as long as the deep draft ships go to the northern-most anchorages.

(f) Maximum separation between occupied anchorages perpendicular to expected wind direction will minimize the damage threat should ships break loose.

5.4 EVASION AT SEA

Evasion at sea is the recommended course of action for bigger ships and carriers when severe tropical storm conditions are expected and for all seaworthy vessels when hurricane conditions are expected. It should be noted that due to the latitude of Norfolk and orientation of the coastline, conditions of this sort (i.e., severe tropical storm/hurricane) are rare at the piers and would normally only be expected if an intense tropical cyclone was threatening to track close with a limited overland trajectory. When evasion is contemplated, the importance of correctly assessing the threat posed by the storm and acting quickly so as to retain flexibility cannot be overemphasized. The nature of the coastline makes an early departure imperative if a real threat is in the offing.

The decision to sail, once taken, poses a new problem of the best course of action once at sea. The commanding officer with his detailed knowledge of his ship and crew, must always make his own personal decision as the situation dictates. The following describes the most likely threat situations and the recommended courses of action. In reality, of course, each threat must be considered on its own merits.

(a) A tropical cyclone moving along the coast from the Florida area and forecast to pass to the east -- this undoubtedly is the commonest threat and carries the possibility of high surges. Unfortunately it is also the most difficult to evade. First an early departure is imperative in order to cross ahead of the storm as there is little choice but to steam due east in order to obtain sea room in which to maneuver. This is likely to be followed by steaming southeast to avoid the likelihood that the storm will recurve on to a northeasterly track and accelerate.

(b) A tropical cyclone moving up from the Florida area and forecast to pass to the west of Norfolk -- this situation is less common and does not pose as big a threat as case (a). The winds produced by the cyclone at Norfolk would generally be southeasterly veering to westerly as the cyclone passed. In order to justify evacuation, the expected CPA would have to be very close, say within 60 n mi, or the cyclone would still have to be very intense, an unlikely situation after a long land track. Evasion is also relatively easy. After leaving Chesapeake Bay, ships should steam southeast.

(c) A tropical cyclone moving northwest and forecast to pass north or within 100 n mi south of Norfolk -- although such a threat is rare, it has happened in the past, and has caused the worst conditions ever recorded (August, 1933). Early evasion would be to steam past Cape Hatteras and escape southwestwards towards Florida, before the seas ahead of the storm built up sufficiently to impair the ship's advance. Also the wind and seas would be from astern and relatively favorable. For those who delay the evasion decision in this case, problems will mount rapidly. If the evasion route around Cape Hatteras becomes impossible, there is no choice but to steam northeastwards into headwinds and seas. Progress will be slow and the cyclone may well recurve towards the north to make matters worse. It would be preferable to go to the hurricane anchorage in this situation.

Other cases will have to be considered individually. Also, a close watch must be kept on all warnings even after the danger has apparently passed. There is always a possibility of a tropical cyclone stalling, or looping to rethreaten a particular location.

5.5 RETURNING TO HARBOR

After the passage and successful evasion of a tropical cyclone, returning to harbor is itself not without hazard. There may well be sunken wrecks in the channels, there may be damage to the piers and normal alongside services may well be disrupted. There is also a high probability that channel markers and other navigation aids have shifted position or have become otherwise unreliable. The utmost caution must therefore be taken.

6. ADVICE FOR SAILING BOATS AND SMALL FISHING VESSELS

Sailing boats and small fishing vessels obviously must seek shelter in a harbor whatever the expected wind conditions are. The best solution is to remove the boat from the water altogether at the earliest opportunity and secure it well away from the effects of possible surge. For those unable or too late to remove their vessels from the water, they should locate well protected berths or moorings before the start of the hurricane season. Within the Norfolk area there are many tributaries of the Elizabeth River, especially the southern branch where small boats can find shelter. It must be remembered however, that the boat should be tended throughout the threat period in order to prevent the breakage of mooring lines if a surge occurs.

The following are a few of the so-called "hurricane holes" available to small boats around the Chesapeake Bay and is extracted from "The Chesapeake; A Boating Guide to Weather," by Jon Lucy, Terry Ritter and Jerry LaRue published in 1979:

> Although hurricanes are rare in Chesapeake Bay, near-hurricane force winds (greater than 63 knots) are not uncommon because of severe thunderstorm activity and summertime squalls. This makes it important for boatmen to know the location of well-protected harbors that provide good landlocked water with adequate depth for deep draft vessels. So-called "hurricane holes" are present in most Bay tributaries, according to Julius Wilensky in "83 Hurricane Holes of the East Coast" (Sea Magazine, August 1978). Locations of hurricane holes follow (Fig. II-17), as recommended by Wilensky and Jon Lucy (indicated by an asterisk).

Chesapeake Bay Hurricane Holes

<u>Lower Bay (south to north)</u>

Western Shore

1) Linkhorn Bay, off Lynnhaven Bay above cape Henry* -- Enter Lynnhaven Inlet cautiously because of a shifting bar, but anticipate a well-marked entrance channel with water depths of 6-10 feet (1.8-3 meters); the Inlet and the east channel towards Linkhorn Bay are crossed by fixed bridges with 35 foot (10.7 meter) clearances; after entering the Inlet, swing wide to the left towards the Great Neck Road Bridge and proceed into Broad Bay, then through the 6 foot (1.8 meter) deep Narrows into Linkhorn Bay; protected anchorages can be found in both the south and east branches of the Bay to either side of Bird Neck Point, with shoreside facilities at the ends of each branch.

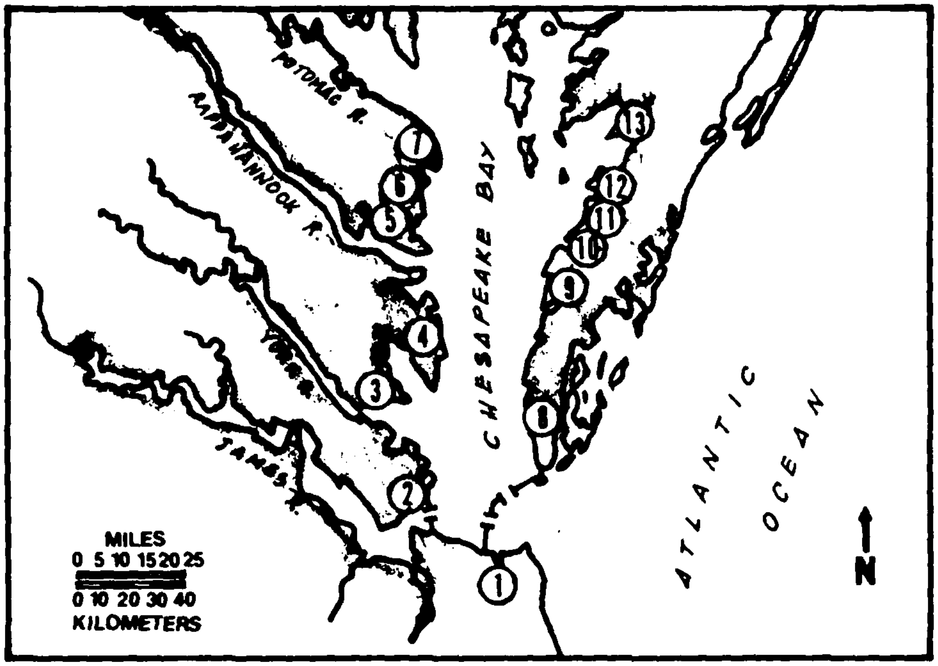

Figure II-17. Some Chesapeake Bay hurricane holes that provide good vessel anchorages during high-wind periods (after Lucy et al., 1977).

2) Hampton River, north shore inside Hampto Roads* -- Cross Hampton Roads Bridge Tunnel and enter the channel to the right behind the Tunnel island; as you enter the mouth of Hampton River, be on the lookout for commercial tug and barge traffic; proceed up Sunset Creek on the left where two marinas handle limited numbers of transient boats; do not anchor in the Hampton River channel because of barge traffic and the River's northeast orientation.

3) Lower York River, north shore* -- after passing Sandy Point, Look for day markers indicating the winding channel into the Perrin River where dockage can be found at the large marina. Drafts of seven feet (2.1 meters) can be accommodated. Even better protection is offered further up the river in Sarah Creek where good anchorages with water depths of 7-8 feet (2.1-2.4 meters) are available in the northwest branch up to the repair yard and marina, and the northeast branch as far as the oyster packing house on the north shore.

4) East River, off Mobjack Bay -- Anchor either in Putam Creek or in East River itself, south of Woodas Point.

5) Corrotoman River, lower Rappahannock River, north shore -- After clearing the power cables (50 foot or 15.2 meter clearance) along the Grey's Point bridge, anchor in either of the Corrotoman's branches; 7 foot (2.1 meter) drafts can be carried 2 1/2 miles (4 kilometers) up the east branch, while the west branch can handle 8 foot (2.4 meter) drafts for the same distance.

6) Dividing Creek, north of Fleets bay, about midway between Rappahannock and Potomac Rivers -- Anchor up the creek just above Lawrence Cove.

7) Horn Harbor, about 5 miles (8 kilometers) up Great Wicomico River, north shore -- This is the best of several well protected creeks going upriver.

Eastern Shore

8) Cape Charles Harbor* -- This harbor of refuge located nine miles (14.5 kilometers) north of the Cape itself can provide protection with transient docks located in the northeast corner behind the Coast Guard Station; for boats drawing less than five feet (1.5 meters), Kings Creek just north of the harbor also offers protection as well as marina services, but the channel markers must be followed carefully.

9-10) Occohannock and Nandua Creeks* -- Some protection can be found in Occohannock Creek up to the area of Davis Wharf, beyond which water depths drop below 7-8 feet (2.1-2.4 meters). Nandua Creek to the north has a somewhat tricky, winding channel bordered by shoals, but with care, protection can be found by running up to Nandua.

11-12) Pungoteague and Onancock Creeks* -- Good protection is found up Pungoteague Creek in the area of Harborton; further north Onancock Creek provides good storm anchorage in the area of the Onancock town dock.

13) Saxis, upper Pocomoke Sound* -- Protection is available in the commercial fishing harbor for boats requiring depths of 6 feet (1.8 meters) or less.

The anchorages mentioned here may be crowded because of their popularity. If you must look elsewhere for good protection, look for bodies of water in which an extra high tide up to 12 feet (3.7 meters) above mean high water can be handled. If you are actually expecting the eye of a hurricane to come ashore in your area, the best protection in the Northern Hemisphere is in the left rear quadrant with respect to where the storm's eye is expected to intersect the coast (determine the left rear quadrant while facing away from the approaching storm along its projected track).

In seeking protected anchorages, remember that a hurricane usually will produce east or northeast wind speeds of 70-100 knots, follows by lesser winds from the west or northwest. A hurricane's high winds and tides also require that anchor line scope be increased from the usual 7:1 ratio to a 10:1 ratio. If a protected harbor has limited swing room for anchored craft, two anchors should be used 180 opposed to each other. Reduce the likelihood of dragging by anchoring in sand or hard mud rather than grassy bottom or soft mud.

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III: CONTENTS

III. CHARLESTON, SOUTH CAROLINA

SUMMARY

Despite the practical rule (p. 79, United States Coast Pilot 4) -- "When there are indications of a hurricane, vessels should remain in port or seek one if possible." -- this study concludes that Charleston Harbor offers few of the characteristics of a haven during hurricane-force winds (greater than 63 kt). All ships should evade at sea, or if at sea, seek shelter elsewhere. In severe tropical storm conditions (winds 50-63 kt), some moorings along the Cooper River, Shipyard Creek, and Town Creek may be adequate for most ships, but ships with large sail areas should evade at sea. Smaller vessels, fishing boats and sailing craft, and those ships disabled by maintenance should stay fast or seek shelter at facilities at Charleston proper, along the west side of Cooper River and Town Creek, northward of the Battery; North Charleston, along the west side of Cooper River; and in Shipyard Creek. While there is an anchorage for deep-draft vessels in the triangle westward of the confluence of Rebellion Reach of the main channel with South Channel, use of this anchorage during hurricane force winds is not recommended because of:

(a) The restricted scope when riding at anchor.
(b) The hazards of accidental conflict with other shipping during severe storm conditions.
(c) The difficulty of leaving the anchorage, if necessary, against winds and tides that restrict maneuvering.

These conclusions are primarily based on the topography of the area, which is almost flat and near sea level, providing very little sheltering from the wind and especially little protection from storm surge and accompanying wave action.

It is recommended that ships take action as described above at an early stage because of the particularly difficult planning of departure scheduling for tide stage prior to evading at sea. The other argument presented for an early departure involves the concave configuration of the coast line and climatological storm tracks which combine to restrict evasion course options.

To illustrate the need for an early sortie decision RADM D. P. Hall, Commander Submarine Group Six, Charleston, SC in a memorandom of 6 February 1981, points out that an irrevocable decision may be required as much as 44 hours before the expected onset of 50 kt winds.

"All sorties and berthing changes must be completed 18 to 20 hours before the 50 kt wind circle reaches Charleston. Calculate time of low tide transit and estimate the last reasonable underway for the two deep-draft tenders; back up 12 hours earlier, this is a first estimate of the decision time for the Senior Officer Present Afloat to direct sortie for the two tenders. Any later and evasion time would be minimal."

This hurricane haven evaluation was prepared by J.D. Jarrell, R.C. Slusser, A.B. Lund, and R.E. Englebretson of Science Applications, Inc. (SAI), Monterey, CA 93940.

1. GEOGRAPHIC LOCATION

Figure III-1 shows the general areas of Charleston, on the coast of South Carolina where the Ashley, Wando and Cooper Rivers meet. Significant naval activities are depicted.

2. THE HARBORS AND THEIR FACILITIES

2.1 NAVAL WEAPONS STATION

The Naval Weapons Station (Figure III-1) is located about five miles north of Charleston Naval Shipyard on the west bank of the Cooper River. Berth Alfa is 1100 ft long and Berth Bravo is 970 ft long.

2.2 ARMY TRANSPORTATION DEPOT

The Army Transportation Depot (Figure III-1) is located about two miles north of the Charleston Naval Shipyard on the west bank of the Cooper River. The Army Transportation Depot pier is 1500 ft long.

2.3 NORTH CHARLESTON TERMINAL

North Charleston Terminal (Figure III-1) is located about 1.3 miles north of Charleston Naval Shipyard on the west bank of the Cooper River. The North Charleston Terminal is about 2460 ft long with a 12-ft deck height.

2.4 CHARLESTON NAVAL BASE

The Charleston Naval Base (Figure III-1) is located on the west bank of the Cooper River about five miles north of the City of Charleston proper. Located within the confines of the base are the Naval Supply Center, the Naval Station, Charleston and the Naval Shipyard facilities. These activities provide the primary berthing, logistics and repair services to U.S. Navy ships in the Charleston area.

2.5 COLUMBUS STREET TERMINAL

The Columbus Street Terminal (State Pier 8) is located about 1.8 miles north of the battery on the west bank of Town Creek. The wharf is 3,442 ft long with a deck height of 12 ft.

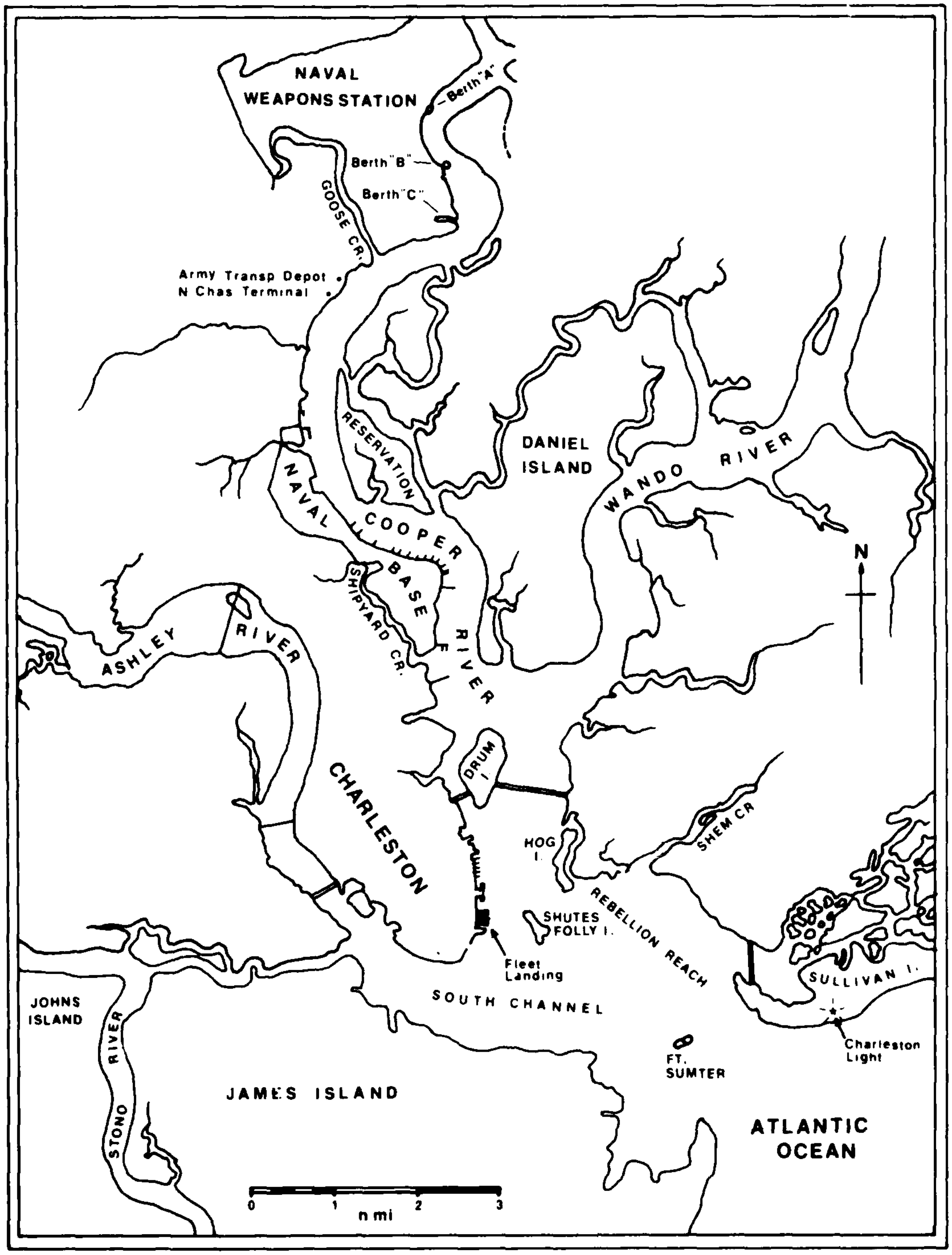

Figure III-1. Area naval activities at Charleston, South Carolina.

2.6 UNION PIER

The Union Pier (State Pier 2) is about 0.8 miles north of the battery on the west bank of Cooper River. The wharf is 1,405 ft long with a 12-ft deck height.

2.7 SHIPYARD RIVER TERMINAL

The Shipyard River Terminal Co. Wharf is located on the south side of Shipyard Creek just inside the entrance. The wharf is about 400 ft long with a 14-ft deck height.

2.8 REFERENCES AND CHARTS

The reader is referred to the following publications for details of the harbor and its facilities:

DMA Hydrographic/Topographic Center, 1979, Publication 940, Chapter 7, Fleet Guide to Charleston.

DMA Hydrographic/Topographic Center, 1979, Chart 11524, Charleston Harbor.

DMA Hydrographic/Topographic Center, 1978, Chart 11521, Charleston Harbor and Approaches.

U.S. Dept. of Commerce, 1980, United States Coast Pilot 4, Atlantic Coast, Cape Henry to Key West.

3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

3.1 TUG AVAILABILITY

Commanding officers of vessels who may be required to shift berth, move to an anchorage or put to sea in the event of a tropical cyclone affecting the Charleston area should bear in mind that the services of the limited number of tugs will be at a premium before and after the passage of a tropical cyclone. Demand for tugs will be particularly high at certain stages of the tide and during normal working hours. Calls for towage assistance, especially for smaller vessels, should therefore be kept to a minimum and planned well ahead.

3.2 HURRICANE ANCHORAGE

Anchorage for deep-draft vessels is available in the triangle westward of the junction of Rebellion Reach of the main channel with South Channel (Figure III-1). However, if that anchorage is used, a scope of 10:1 (rather than the

customary 7:1) should be used and a second anchor should be ready for use. This anchorage is not considered a good hurricane anchorage due to the poor holding quality and confined harbor space.

4. TROPICAL CYCLONES AFFECTING CHARLESTON

4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Charleston is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Charleston in some way, so to some extent this criterion is arbitrary. Meteorological information on tropical cyclones that passed near Charleston is available as far back as 1886. Historical information on storm effects go back to 1686 (see Appendix).[1] Data for the period (1886-1979) are used to generate the probability of passing within 180 n mi, average time to closest point of approach (CPA) and direction of approach information, which will be presented. A subset of this data (1945-1979) was used to devise information on tropical cyclone center positions when strong winds were first and last recorded at Charleston. The selection of this particular time period relates to the availability of hurricane reconnaissance and hence acceptable wind estimates within the cyclone.

Although tropical cyclones have occurred in the North Atlantic during all months of the year, the majority of those which threaten Charleston occur from June through October. A few have occurred in May, November and December. None have affected Charleston in January through April in the period of 1886 through 1979. Figure III-2 depicts the monthly summary of the occurrence of tropical cyclones affecting Charleston based on data for the 94 years, 1886-1979. Of the 142 tropical cyclones which threatened Charleston in this period (less than two threats per year), 135 occurred in the months of June through October with the peak threat in September and October. June through October is considered the normal hurricane season for the North Atlantic Ocean.

Figure III-3 displays the storms affecting Charleston as a function of the compass octant from which they approached. The circled numbers indicate the number of cyclones which approached from that octant. The open numbers represent the same information as a percentage of the total. (Totals are slightly

[1] Ludlum (1963); Purvis (1980); Aldregh (1936); Dunn and Miller (1964).

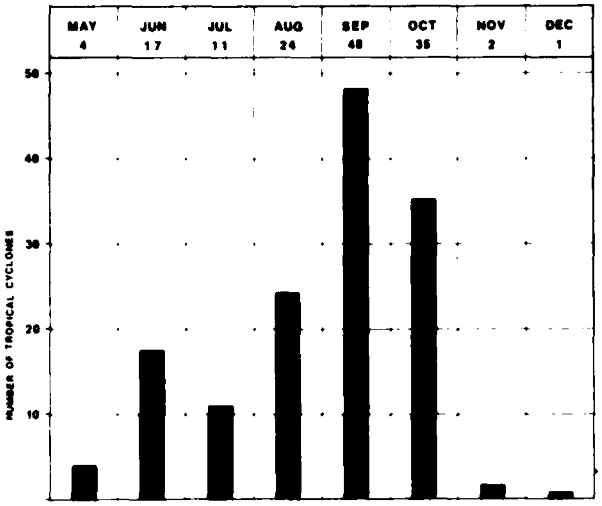

Figure III-2. Frequency distribution of tropical cyclones that passed within 180 n mi of Charleston during the period May-December, with the monthly totals shown at top (based on data from 1886-1979).

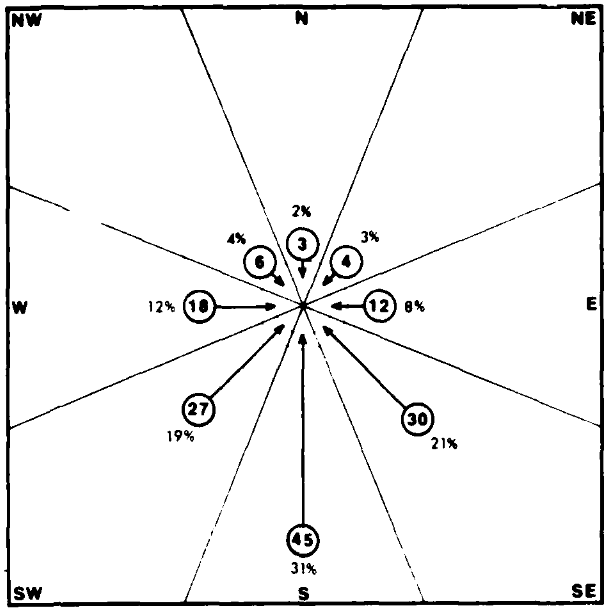

Figure III-3. Directions of approach of tropical cyclones toward Charleston during May-December (based on data from 1886-1979) that passed within 180 n mi of the port. Circled numerals show the number of storms approaching from each octant and percentages show percent of total sample from each octant.

different from Figure III-2 since looping storms may approach more than once.) It is evident from this figure that the major threat of tropical cyclones approaching Charleston is from the south.

An average of 1.5 tropical cyclones per year threaten Charleston. Since Charleston lies at a mid-latitude (33°N) many of these cyclones have completed the recurvature process (i.e., they have turned from a westerly track onto a northerly or northeasterly track). Following the recurvature process, tropical cyclones tend to accelerate their forward movement to an average speed of 16-18 kt in this region. These fast post-recurvature speeds are typical of tropical storms approaching from the south and southwest. Those tropical cyclones which pass on a westerly or northwesterly track have an average forward speed of only 10-12 kt in this region.

A consequence of Charleston being situated on the east coast is that tropical cyclones which pass to the west tend to have a longer overland track than those which pass to the east, or those which approach from the southeast. As soon as a tropical cyclone passes over land, its energy source is drastically reduced and rapid weakening follows. Thus the direction of the threat approach is of utmost importance in the Charleston situation.

Figures III-4 through III-8 are a statistical summary of threat probability based on tropical cyclone tracks for the years 1886-1979[2]. The data are grouped by months to nearly equalize occurrences: January through June, Figure III-4; July and August, Figure III-5; September, Figure III-6; and Figure III-7, October through December. Figure III-8 is for the whole year. The solid lines represent the "percent threat" for any storm location. The heavy lines represent approximate approach times to Charleston. This is based on a smoothed analysis of the average time to CPA of all tropical cyclones that eventually passed within 180 n mi of Charleston. For example, in Figure III-6, a tropical cyclone located at 25N, 85W has approximately a 50% probability of passing within 180 n mi of Charleston and would reach Charleston in 2-3 days if the speed remains close to the climatological normal.

Through the year there is a shift or rotation of the axis of threat to Charleston. In the pre-hurricane season months January to June (Figure III-4) the threat axis is nearly a straight line out of the central Gulf of Mexico and across the western Florida panhandle. In the first half of the season, July and August, the main threat axis has shifted markedly to the Caribbean. The axis is evident in Figure III-5 north of the Leeward Islands, just north of the Bahamas and then off the Florida coast to Charleston. In September the Caribbean remains dominant but both source regions are active as indicated by a double axis in Figure III-6. The Caribbean axis has shifted slightly south and west. In the late season (largely October) there is evidence of a third source of threat south of Florida and northward along the Florida Gulf coast. In Figure III-7 all three axes are evident but the emphasis is shifted back to the Gulf of Mexico where mean tracks from south of Florida combine with those originating in the Gulf.

The annual picture (Figure III-8) retains the three axis configuration with a slight dominance of the Caribbean as the major threat source.

4.2 WIND AND TOPOGRAPHIC EFFECTS

In the 35-year period from 1945-1979, a total of 59 tropical cyclones approached within 180 n mi of Charleston. A tabulation of the intensity of these tropical cyclones at their CPA to Charleston is presented in Table III-1. The data are also separated according to whether the tropical cyclone passed to the east or west of Charleston, and consequently whether it gave generally northerly or southerly winds. It can be seen from Table III-1 that a significant preponderance of the hurricane force tropical cyclones pass to the east to give northerly winds. The reason for this, of course, is that the cyclones

[2]Track information was obtained from Neumann et al., 1978.

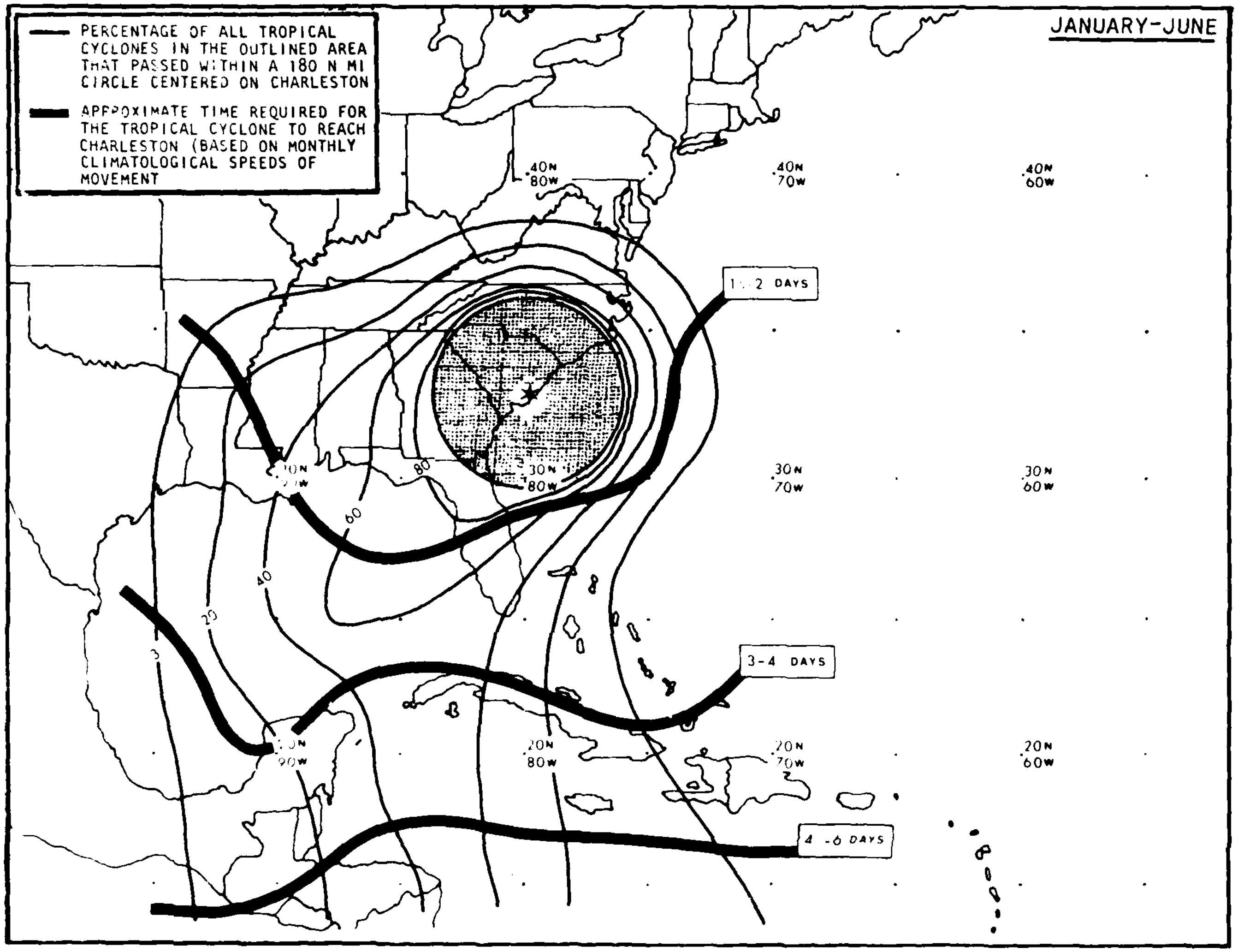

Figure III-4. Probability that a tropical cyclone will pass within 180 n mi of Charleston during the months of January-June (based on data from 1886-1979).

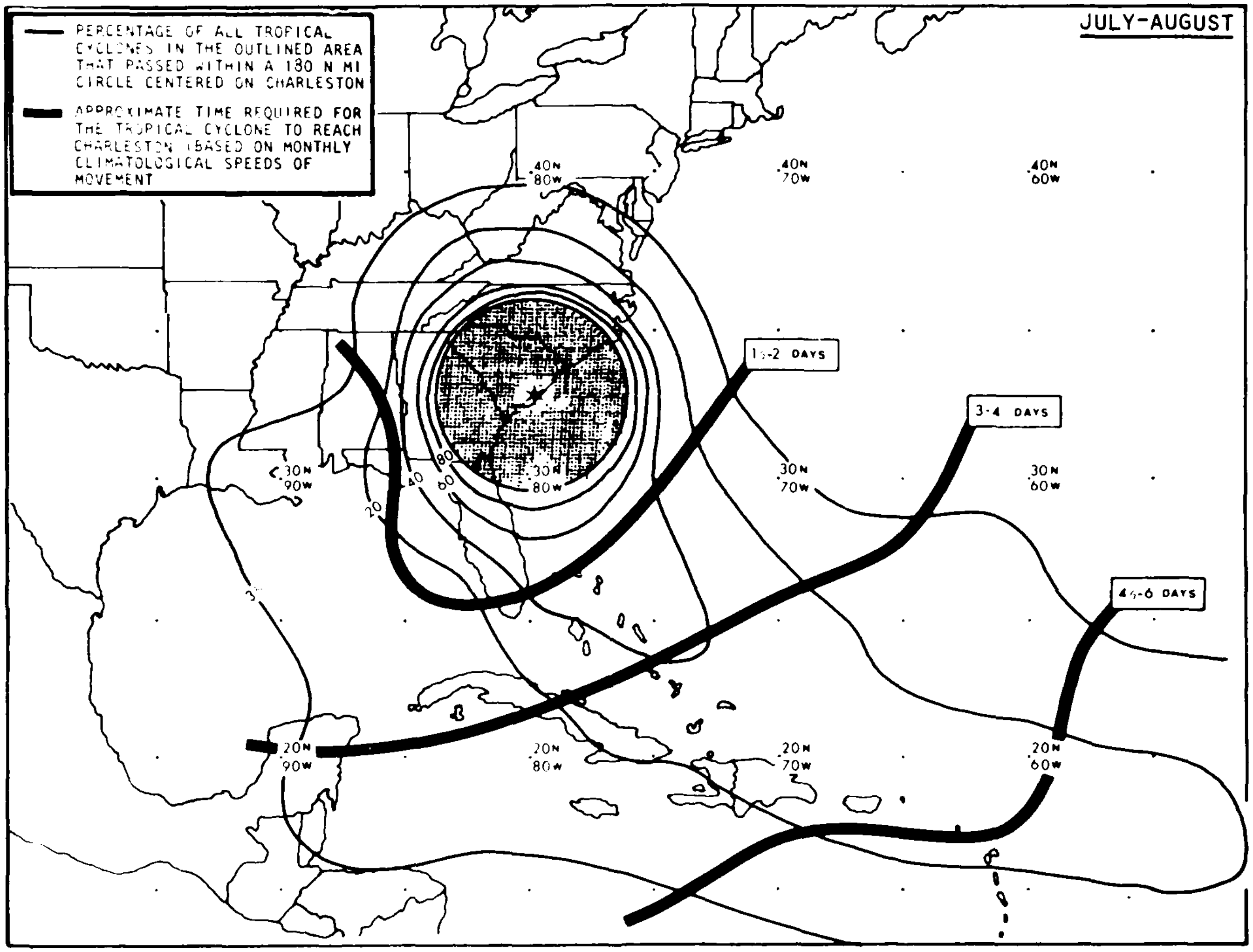

Figure III-5. Probability that a tropical cyclone will pass within 180 n mi of Charleston during the months of July and August (based on data from 1886-1979).

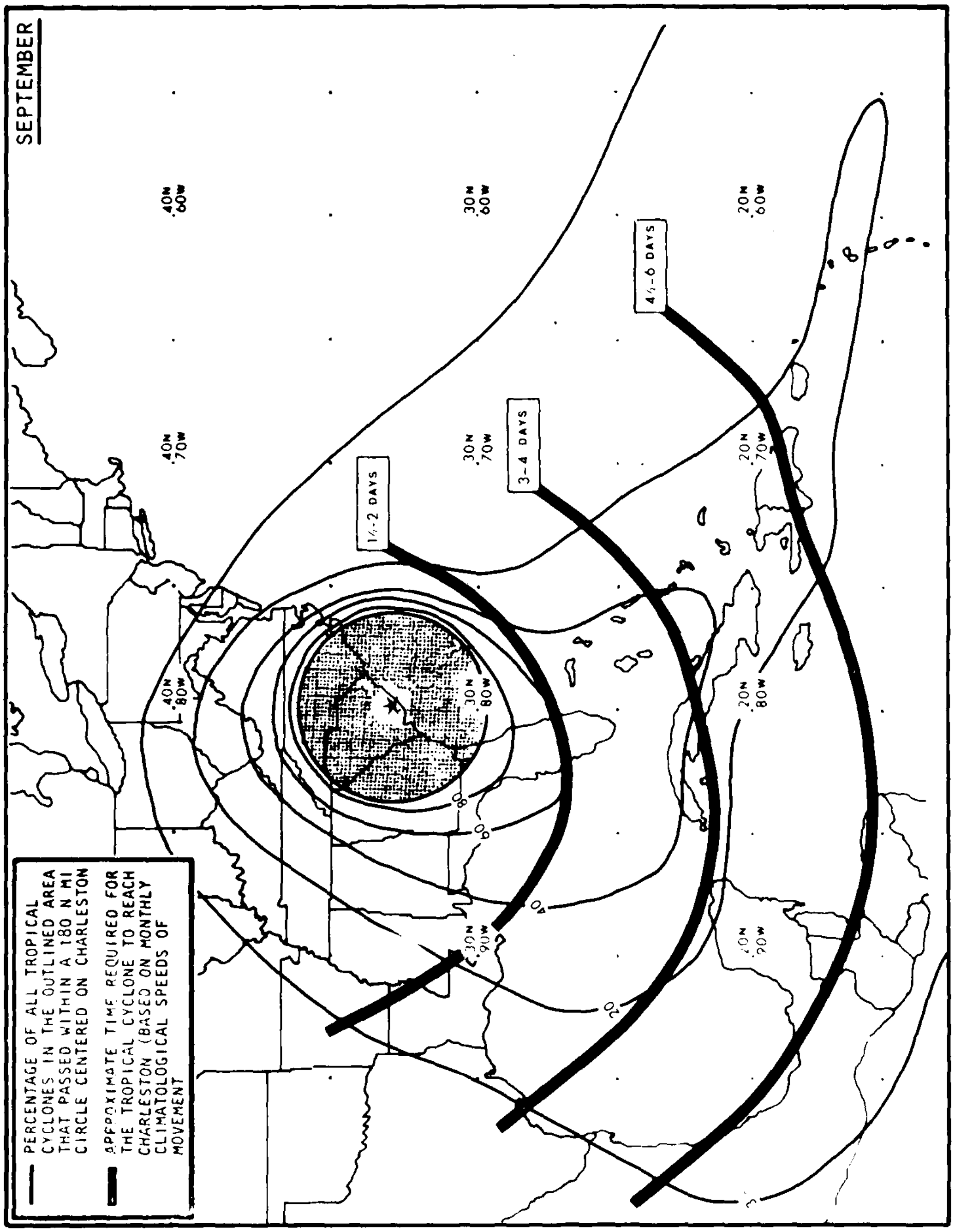

Figure III-6. Probability that a tropical cyclone will pass within 180 n mi of Charleston during the month of September (based on data from 1886-1979).

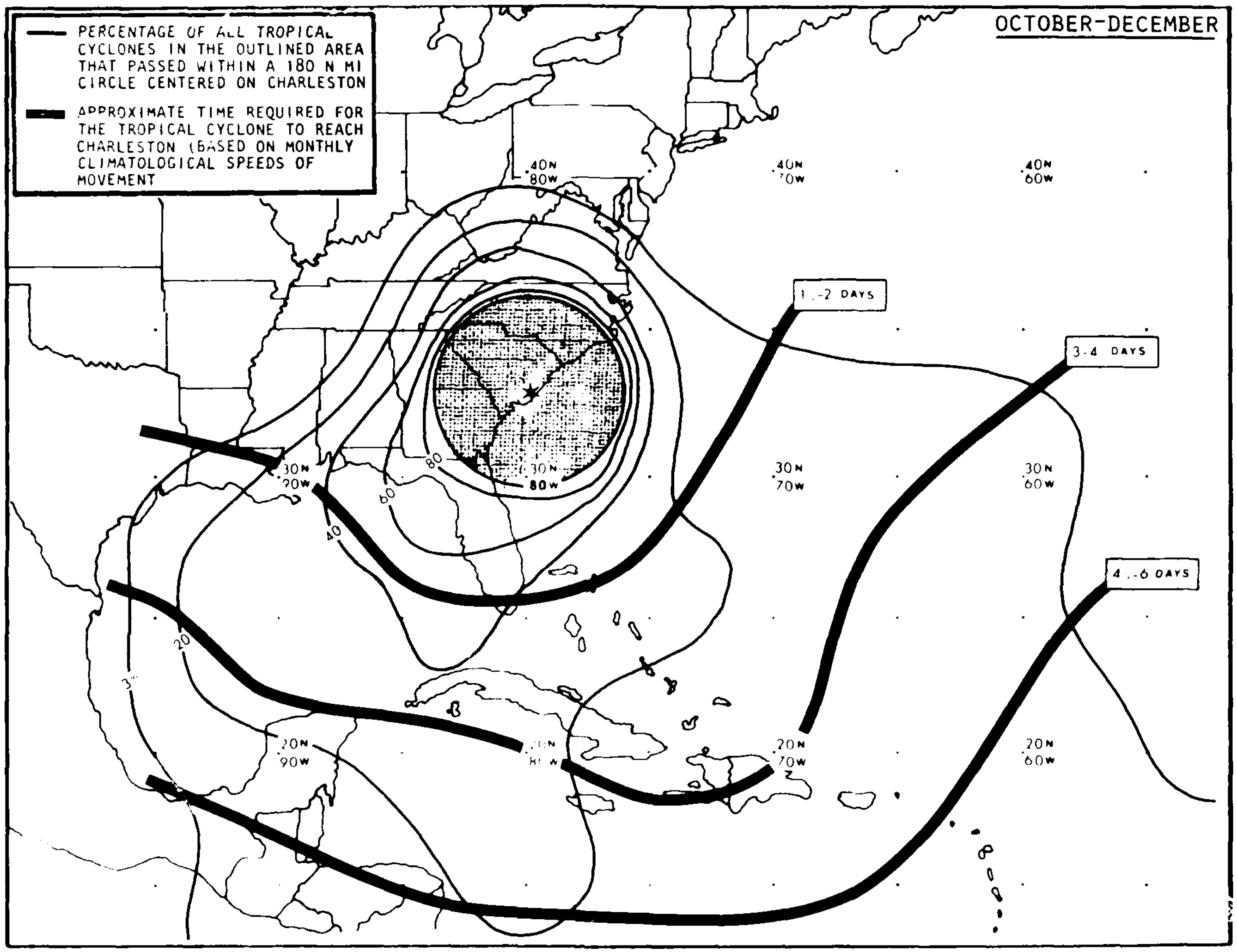

Figure III-7. Probability that a tropical cyclone will pass within 180 n mi of Charleston during the months of October-December (based on data from 1886-1979).

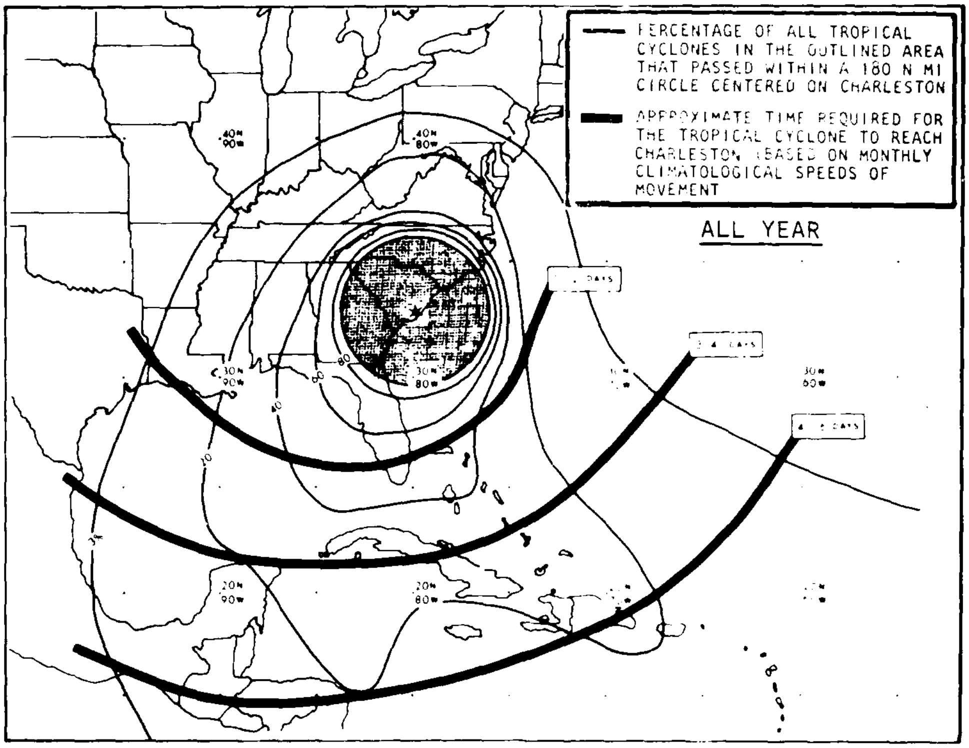

Figure III-8. Annual probability that a tropical cyclone will pass within 180 n mi of Charleston (based on data from 1886-1979).

Table III-1. The 59 tropical cyclones which threatened Charleston between 1945 and 1979 classified by intensity at closest point of approach (CPA) and whether they passed to the east or west.

Passed	Hurricane	Tropical Storm	Tropical Depression	Extratropical/ Subtropical
East	12	10	11	1/3
West	2	6	9	3/1

that pass to the east tend to have had a longer and more recent sea track and therefore have tended to maintain their intensity. Those tropical cyclones which pass to the west of Charleston tend to have had a long overland track and therefore are usually weakened.

Out of the 59 threat tropical cyclones, 28 produced winds of 22 kt or stronger at Charleston. Six of those 28 produced winds of 34 kt or stronger. The complete tracks of those six are shown in Figure III-9. It appears, therefore, that tropical cyclones of full hurricane intensity are relatively uncommon events at Charleston. Observational records from the Charleston Airport for the 1945-1979 period show the maximum wind reported as 46 knots in a storm in August 1949. Hurricane force winds would be expected to occur more frequently over the open ocean and exposed coastlines in the Charleston area. This observation should be of small comfort since records show destructive winds of 76 mph in 1916, 120 mph in 1893 and 80 mph in 1885 at Charleston (see Appendix).

4.3 WAVE ACTION

The Charleston Harbor is not normally susceptible to wave action because of its location, entirely within the lower portion of the Ashley, Cooper and Wando Rivers. It is protected from the open ocean swell and wind wave systems by jetties, above and below water, which extend about 3 n mi seaward on either side of the main channel. The river mouth provides a narrow harbor entrance between Morris and Sullivans Islands. However, this protection is greatly reduced when storm surge tops the barriers of islands, jetties, etc., and then wave action in the harbor and a secondary surf zone near the city can be expected.

4.4 STORM SURGE AND TIDES

Storm surge can be defined as the difference between observed water level and expected water level at a given location during storm conditions. Storm surge varies considerably in this area even over quite short distances due to the highly variable bathymetry and shoreline shape. Other factors related to the storm track and strength, which affect the water level are: direction, speed and persistence of the wind; the atmospheric pressure; water transport by waves and swell and rainfall. Of course a major consideration is the stage of the tide. The actual surge to be expected, therefore, will be difficult to forecast. The National Weather Service has developed computer prediction models, and will issue storm surge forecasts as appropriate. The approximate surge heights to be expected can be estimated from past experience. Water levels of 13 ft above mean low water (MLW) were recorded at Water Street during the 1893 and 1911 hurricanes. A high water level of 17 ft above MLW was recorded in the 1852 hurricane. Such a surge would not only be a disaster for many ships, but for the low-lying land it would be a catastrophe. The SPLASH storm surge model operated by National Oceanic and Atmospheric Administration (NOAA) predicts a surge as great as 24 ft could occur at the harbor entrance

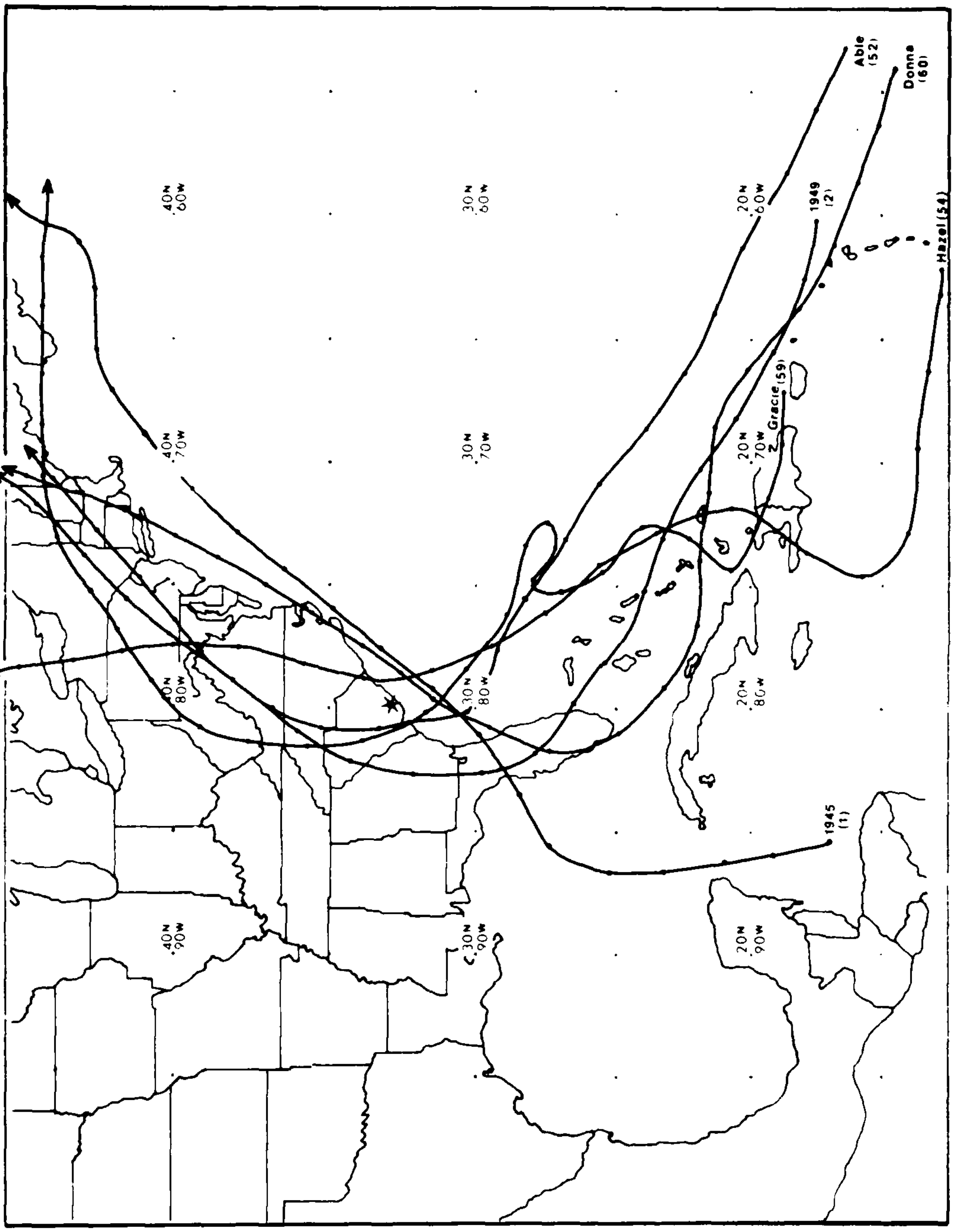

Figure III-9. Tracks of the tropical cyclones that produced gale force winds ($\geq$34 kt) at Charleston (based on data from 1945-1979).

under "worst case" conditions. A preliminary study by the Corps of Engineers propagated a surge up the Cooper River 18 miles to the Naval Weapons Station (NWS). In that study a standard project hurricane surge of 17.5 ft at the harbor entrance was expected to have fallen off by only 2.5 ft (to 15 ft) at the NWS.

The implication for ships moored along the river, in terms of stress on lines and being lifted atop piers, is quite clear.

Typical spring tides for the Charleston area are 6 ft above MLW at high tide and one foot below MLW at low tide for a range of 7 ft. The mean range is about 5 ft. The tidal current off Fort Sumter is up to 3.5 kt with flood tide toward 335°T. The normal maximum tidal currents in the harbor entrance during flood tide is approximately 2 kt and approaches 3 kt on ebb tide. This tidal action would be accentuated by storm surge.

5. THE DECISION TO EVADE OR REMAIN IN PORT

Specific instructions to Navy ships for dealing with severe weather are laid down in SOPA (ADMIN) CHASINST 5400.1 series. A definition of Tropical Storm/Hurricane Conditions I through IV is also given, together with the expected status of preparedness and action required to achieve each condition of readiness. Other sources of information on hazardous tropical cyclone weather and readiness actions are:

Fleet Guide, Pub. 940, Chapter 7
OPNAVINST 3140.24 series
CINCLANTFLTINST 5400.2 series
Naval Warfare Publication Four (NWP 4)

The evasion rationale should be based on consideration of 3 general factors: vessel characteristics, harbor conditions and the forecast viewed within the context of storm climatology. Individual vessel factors are best determined by those responsible for each vessel. Interpretation of harbor and climatology factors are addressed in the following section.

5.1 EVASION RATIONALE

Evasion at sea is the recommended course of action for all seaworthy vessels when Charleston is directly threatened with destructive force winds and/or inundating severe storm surge from an intense tropical cyclone or hurricane. This rationale is based on the lack of terrain features that could provide shelter, the lack of anchorages suitable for use during a hurricane, and the over-riding concern for the effects of a strong storm surge.

A critical aspect of the decision to sortie from this particular port is its timeliness. The decision should ideally be made 36-48 hours before the onset of gale force winds (near the time of the decision to set Condition III). The need for early sortie from Charleston is a result of the coastline orientation, the nature of the harbor makeup, the distance to deep water for submarines, and is a function of storm intensity. The somewhat concave shape of the southeastern U.S. coastline restricts running room to the north and south. The northeastward-aligned coastline, to the north, and the south-southeastward-aligned coastline of Florida, limit the maneuvering options when evading in those directions. Taking an easterly course results in crossing the track (crossing the T)[3] of all storms that recurve or pass north of Charleston; in addition, it places the ship in the dangerous semicircle of the storm. A course north of east could place the ship in a position of being overtaken by a fast-moving recurving storm. Evading to the south, while positioning the ship in the less dangerous semicircle, results in very limited maneuvering space because of the eastward curvature of the Florida Atlantic coastline. Furthermore, for those storms which do not recurve but assume a more westerly course, evasion to the south can create a dangerous situation because of the closing storm and limited evasion routes. If sortie has not commenced (SOPA issues order) within 24 hours of the expected arrival of 30 kt winds, a firm commitment to remain in port should be made. The need for the early sortie is further necessitated by the general characteristics of a multi-river harbor, i.e., distance to harbor mouth, limited navigable water, bends in the channel, bridge obstructions, converging traffic at confluence of rivers, and the outflowing river current requiring greater speeds in order to maintain steerage without the assistance of a flood tide. All of these factors can come into play in departing the Charleston Harbor. These harbor characteristics, plus the tendency for a strong storm surge, make late efforts to sortie or change berthing/anchorage the worst possible position to be caught in. The following guidance is offered for consideration:

a. Sortie Not Recommended. It would be difficult to justify sortie for any storm which approaches overland (North Florida, Georgia) from west of 82°W. Because of the overland route the storm's primary energy source has been depleted; this, coupled with the higher surface frictional forces, results in rapid weakening of tropical storms. However, such storms can drop a significant amount of rain, capable of raising river levels. Overland storms also have limited opportunity to reintensify before reaching Charleston unless, of course, they move off the east coast of Florida after crossing the peninsula. If they

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[3]Somervell and Jarrell, 1970.

reintensify over water, there is generally not enough time for sortie. Winds may then be of some problem but there is little risk of significant surge from this type of storm. Finally, sortie is not advised for tropical cyclones with less than 50 kt center winds unless they are forecast to significantly strengthen to hurricane strength.

b. Sortie Recommended. Sortie is recommended for all intense or developing hurricanes that are approaching on over-water tracks and are expected to pass "close" to Charleston. "Close" is a variable; it is a function of the distance that strong winds extend from the storm center, with an allowance for error. A forecast of a 250 n mi CPA for a hurricane with maximum sustained winds of 150 kt may be "close" whereas a 100 n mi CPA of a 55 kt storm may not be "close". All storms forecast to pass within 180 n mi of Charleston are a threat, but those storms approaching from the sector between a bearing of 120^{0} true (the axis of the entrance channel) from Charleston clockwise to the Atlantic coast south of Charleston pose the greatest threat. A storm within this sector, moving northwest and expected to make landfall close to Charleston is the most threatening situation. These storms tend to be the most intense and also produce the earliest and highest storm surge. Considering only recent climatology for Charleston in making hurricane preparation decisions is being shortsighted. Those recent storms of disastrous potential have either made landfall at low tide, at such a small angle to the coast, or too great a CPA to produce the great winds and surge of past major hurricanes.

c. Other Cases. There are two "other" cases not covered in the "sortie", "stay" risks above. These are:

(1) A tropical cyclone approaching from north of a 120^{0} bearing from Charleston.

(2) A tropical cyclone over land but east of the 82nd meridian.

Either of these cases can be dangerous. The first was excluded only because this type rarely affects Charleston. One which is forecast to approach Charleston should be treated as if it were south of the 120^{0} bearing except for evasion tactics (see Section 5.4). The second group was excluded because the actual track overland can be as little as 10% or as much as 100% of the remaining distance to Charleston. Ten percent of a two-day track being overland is probably sufficient to prohibit important strengthening but will not usually cause decay. Thus weak cyclones (<50 kt) with an expected short overland or major hurricanes with a long overland track are "stay" cases. On the other hand, strong hurricanes and a possible short overland track combine to create conditions justifying a sortie.

5.2 REMAINING ALONGSIDE BERTHS

Remaining in port when the means to evade a storm are available is a decision contrary to most of the traditional rules of seamanship, notwithstanding the United States Coast Pilot 4. However, the final decision will depend on many parameters including the forecast wind speed at the port and the track of the storm. Characteristics of the individual harbor and vessel must also be taken into account. The following should be considered.

5.2.1 Naval Weapons Station

(a) Preliminary studies indicate that the height of a storm produced surge 18 miles up the Cooper River will only have decreased by about 2 ft from the surge height at the mouth of the Charleston Harbor. Surge heights of approximately 13 ft were recorded at Water Street during the 1911 and 1893 hurricanes (based on newspaper article shortly after 1911 storm).

(b) Because of their masthead height, the submarine tenders can only clear Cooper River Bridge at, or near, low tide. The increased water level with the storm surge will further limit the movement of the tenders.

(c) Transiting downstream may require speeds to 15 kt on an ebb tide in order to maintain steerage around turns.

(d) The Mediterranean-moored (stern to) tender may have to be moved to a safer anchorage.

(e) Submarines must travel 6-8 hours to reach a safe submergence area (55 n mi to 100 fathom curve).

(f) Navy small craft would be moored in Goose Creek.

(g) The emergency sortie plan, prepared by SOPA, may call for ships and submarines at the Naval Weapons Station to sortie <u>after</u> those at the Lower Charleston Harbor, Fleet Piers and Naval Shipyard. This will depend on SOPA's analysis of the situation.

5.2.2 Naval Base

(a) The submarine tender at Mike pier would be more protected at a wider pier to allow effective use of spring lines.

(b) Currents which are normally 2-3 kt may be 5 or 6 kt during a water pileup or surge.

(c) Vessels may ride over piers that are relatively low compared to the anticipated extreme surge heights (10-15 ft).

(d) Normal docking conditions relative to ebb and flood tide or slack water will be modified by the storm surge. The surge effect may be felt as much as 24 hours prior to arrival of the storm center.

5.3 ANCHORING IN CHARLESTON HARBOR

SOPA will assign berths in one of the following berthing locations:

Naval Shipyard
NAVSTA Piers
Naval Weapons Station
South Carolina State Port Terminal
Army Transportation Depot
Columbus Street Piers
Clouter Creek
Goose Creek
Union Street Piers
Passenger Terminal
Shipyard Creek

If adequate hurricane berthing is not available for all ships present, SOPA will promulgate a movement order to those ships that are to proceed to sea. Such movement orders will be coordinated with any vessel traffic control orders issued by the Coast Guard Captain of the Port.

There is anchorage space during extreme weather conditions at Rebellion Reach for two medium sized ships and room for two small ships in the south channel. However, the bottom type is soft clay and poor holding should be expected. Main power must be immediately available.

5.3.1 Advice for Small Craft and Atlantic Intracoastal Waterway (AICW) Traffic

Because of the extreme danger of extensive flooding and the historical record of loss of lives on the barrier islands, these islands will be evacuated when there is a storm surge threat. In order to facilitate this action the swing bridges across the AICW on either side of Charleston Harbor will be closed to AICW traffic. This action may take place as much as 24 hours in advance of the storm passage. The Coast Guard Captain of the Port may issue orders for restricting or controling vessel traffic. Such orders will be given wide promulgation by local official and public media.

5.3.2 Small Craft Havens

A number of creeks flowing into the Charleston Harbor offer regions of haven for small craft. The following creeks are listed and comments are offered:

(a) Shipyard Creek: Very good haven but crowded.

(b) Shem Creek: Good haven and convenient for AICW traffic.

(c) Goose Creek: Good haven, used by many small craft.

(d) Yellowhouse Creek: Used by Coast Guard

(e) Clouter Creek

5.4 EVASION AT SEA

Evasion at sea is the recommended course of action for larger ships when severe tropical storm conditions (50-63 kt) are expected and for all seaworthy vessels when hurricane conditions (>63 kt) are expected. When evasion is contemplated, the importance of correctly assessing the threat posed by the storm and acting quickly so as to retain flexibility cannot be overemphasized. The nature of the coastline makes an early departure imperative if a real threat is in the offing.

The decision to sail, once taken, poses a new problem of the best course of action once at sea. The commanding officer, with his detailed knowledge of his ship and crew, must always make his decision as the situation dictates. The following describes the most likely threat situations and the recommended courses of action. In reality, of course, each threat must be considered on its own merits.

(a) A tropical cyclone located within the sector formed between a bearing 120° true from Charleston and the 82nd meridian -- Tropical cyclones approaching from this sector are the greatest threat for both wind intensity and probability of high surges. Some of the worst conditions ever recorded (1752 and 1911 storms)[4, 5] have progressed on this path. They are also the most difficult to evade in that transiting east or northeastward positions the ship in the dangerous semicircle and the region the storm is likely to move into. Early departure is imperative in order to either cross ahead of the storm and obtain sea room in which to maneuver toward the southeast, or outrun the storm to some haven or region to the northeast. The likely action of the storm is to recurve to a northeasterly path and accelerate.

NOTE: The 120° bearing rule appears least reliable in the July-August period. During this time-frame storms near the 120° bearing radial are more likely to continue westward than during other periods.

[4] Aldregh, J. T., 1936.

[5] Charleston newspaper article on August 27-28, 1911 storm.

(b) A tropical cyclone that has passed west of the 82nd meridian and is approaching from Florida or the Gulf of Mexico and forecast to pass close to Charleston -- this situation is the least threatening. The intensity of the storm will have been significantly reduced by the overland passage. Surge buildup will be minimal and evacuation is not recommended. If evasion action were chosen, the best route would be to the southeast. In this special case, it is unlikely that tropical storm-force winds (>33 kt) will occur at Charleston, but it is reasonable that a tropical cyclone can regenerate into a severe threat to ships in the open Atlantic. Thus Charleston (in this special case only) represents a safe haven. All of the previous cautions should be taken into consideration, in that early evasion cannot be effective after tide and storm combine to make it unwise to leave port.

(c) A tropical storm north of the 120^{0} radial from Charleston -- this situation is less common than (a) or (b). Storms that continue on a westward track are a threat to Charleston. Evasion action would be to steam southwestward along the coast. This action would situate the vessel in the less dangerous semicircle.

Other cases will have to be considered individually. Also, a close watch must be kept on all warnings even after the danger has apparently passed. There is always a possibility of a tropical cyclone stalling, or looping to rethreaten a particular location.

5.5 RETURNING TO HARBOR

After the passage and successful evasion of a tropical cyclone, returning to harbor is itself not without hazard. There may well be sunken wrecks in the channels, there may be damage to the piers and normal alongside services may well be disrupted. There is also a high probability that channel markers and other navigation aids have shifted position or have become otherwise unreliable. The utmost caution must therefore be taken. The Coast Guard will conduct harbor surveillance as soon as possible after the storm passes and will issue advisories. Traffic control measures may be imposed as necessary by the Coast Guard Captain of the Port.

6. ADVICE FOR SAILING BOATS AND SMALL FISHING VESSELS

Sailing boats and small fishing vessels obviously must seek shelter in a harbor whatever the expected wind conditions are. The best solution is to remove the boat from the water altogether at the earliest opportunity and secure it well away from the effects of possible surge. All owners should locate well protected berths or moorings before the start of the hurricane season for use in the event they are too late or unable to get their vessels out of the water. Within the Charleston area there are several tributaries of the Ashley, Cooper and Wando Rivers, where small boats can find shelter.

If a surge occurs, untended mooring lines will likely part, leaving small craft in a pile of debris. An owner staying with his craft to tend lines may save his craft at the cost of exposing himself to a life threatening situation.

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APPENDIX: SIGNIFICANT HURRICANES AFFECTING CHARLESTON SINCE 1686

Year	Date	Comments
1686	Sep 4/5	Severe destruction. Many downed trees.
1700	Sep 14	Several ships lost with all hands. Residents took shelter in second stories due to storm surge flooding.
1713	Sep 16	Large storm surge wiped out portions of fort (70 drowned). All but one ship driven ashore.
1728	Aug 13	23 ships lost or damaged. Residents took refuge from flooding in upper stories.
1752	Sep 15	Greatest storm ever at Charleston (CHS). Surge 17 ft above MLW about 2 hours before high tide. Wind shift stopped rise at 17 ft, fell about 5 ft in 10 minute period. All vessels ashore except Hornet man-of-war with 7 anchors out. All wharves and bridges ruined including every building upon them. Passed just south and west, small intense storm. Tide came in like a bore filling the harbor in minutes. Roads so full of trees down that traveling extremely difficult.
1781	Aug 10	Hurricane force winds. Two British ships sunk. Moved along coastal track from Georgia.
1783	Oct 7/8	Considerable damage to wharves. Surge at high tide but wind shifted to northwest to limit flooding and wharf damage.
1792	Oct 31	Considerable damage to harbor. Severe gale at ebb tide.
1797	Oct 19/20	Great damage to shipping. High surge covered all wharves, driving ships into others.
1800	Oct 4/5	Severe storm. Most damage since 1783.
1804	Sep 7	Considerable wharf damage due to surge and wind. 5 ships sunk, 11 severely damaged. Landfall between Savannah and CHS. 500 deaths along coast.
1811	Sep 10	Landfall north. Tornado at CHS.
1813	Aug 27	Severe wharf damage. Sullivans Island inundated 4 to 5 ft. Bridges washed away or damaged. 15 deaths at CHS. Small intense storm, inland just north of CHS.
1822	Sep 27	Landfall to north. Wind damage. Little harbor damage. Tide ranged 6 ft in 45 minutes.
1825	Jun 3/4	Trees and fences leveled.
1830	Aug 15	Landfall nearby or passed close offshore. Violent winds. Wind shift saved Sullivans Island from inundation.

Year	Date	Comments
1834	Sep 4	Passed offshore. Strong winds NW, back to WSW. Trees uprooted and broken off. No ship damage.
1854	Sep 7	Gale winds with violent rain. Damage to wharves and buildings by winds and flooding.
1881	Aug 27	54 mph winds at CHS.
1885	Aug 25	Great hurricane. Landfall near Savannah. Winds 80 mph; 21 lives lost at CHS.
1893	Aug 27/28	Greatest hurricane in 19th century. Landfall near Savannah. 2000 lives lost mostly south of CHS. Surge 12 ft above MLW at CHS; 20 ft at Beaufort. Considerable wharf damage. Winds 120 mph at CHS.
1911	Aug 28	Severe storm. Landfall south. Surge 12-13 ft above MLW.
1916	Jul 14/15	76 mph at CHS. Landfall at Bulls Bay.
1940	Aug 11/15	Landfall near Beaufort. Surge 11.5 ft above MLW at CHS.
1945	Sep 17	Tropical storm. Surge 6.8 ft MLW at CHS.
1952	Aug 31	Hurricane "Able". Landfall near Beaufort. 62 mph gusts at CHS.
1959	Sep 29	"Gracie". Last major hurricane. Landfall at St. Helena Sound at low tide. Surge 8.6 ft above MLW. 62 mph gusts at CHS.
1960	Sep 11	"Donna". Tornado at CHS.
1968	Jun 7	TD or TS "Abby". 10 in rain.
1971	Aug 17	Tropical depression. 12.03 in rain in 48 hours.
1979	Sep 3/4	"David". Tornado at CHS. 8.8 ft above MLW.

NOTE: Data prior to 1886 has been derived largely from narrative-type historical publications rather than direct weather or tidal observations.

IV: CONTENTS

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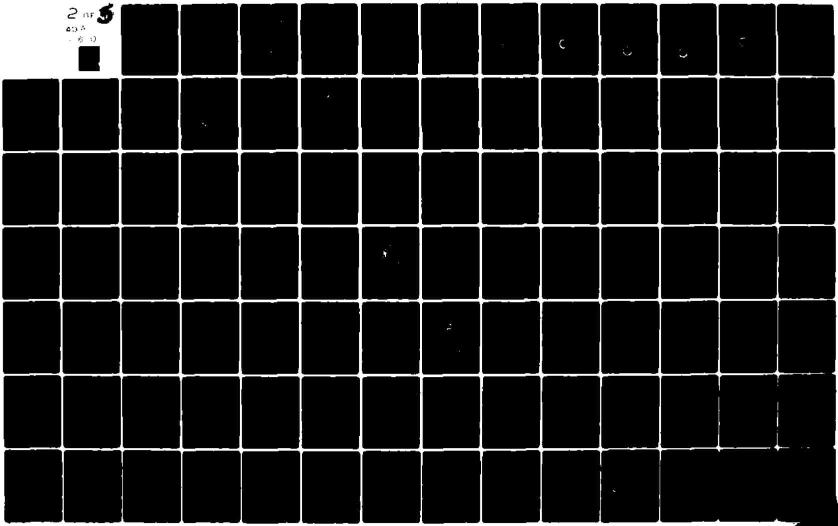

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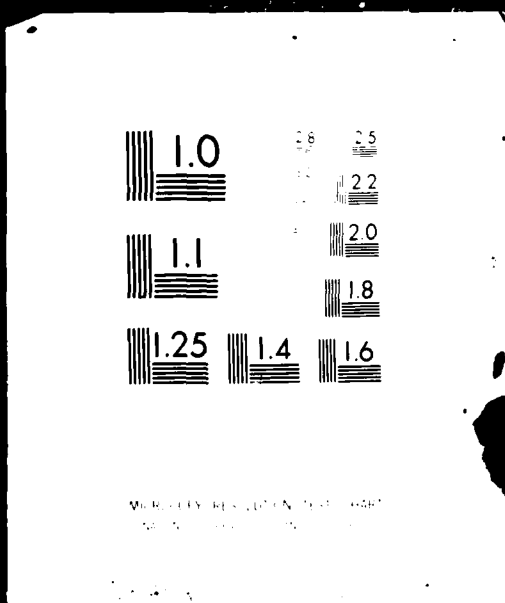

IV. KEY WEST, FLORIDA

SUMMARY

Key West is second only to Pensacola, among those ports of the continental U.S.A. regularly used by the Navy, in the frequency of near passes of tropical storms and hurricanes (Neumann et al., 1978). It is far less prone than other Gulf of Mexico or East Coast ports, however, to the devastating effects of storm surge. Moreover, if threatened by tropical cyclones, there is considerable flexibility in evasion options for ships at Key West, and the port has the potential of providing safe berths and anchorages for vessels of up to 30 ft draft.

Under present circumstances, those port facilities which become important in heavy weather, such as ample tug power or docking and repair capabilities, are so limited that Key West must be regarded as a poor hurricane haven. According to the direction of approach of the threatening storm and its expected passing side and wind effects, criteria have been established to determine whether seaworthy vessels should sortie or remain in port. A detailed climatological analysis of the tropical cyclone threat is presented in the text, together with a rationale for combining this analysis with real-time forecasts for the setting of Hurricane Conditions. This rationale, in conjunction with the guidance for making the leave/stay decision, should minimize the frequency of unnecessary sorties.

For deep-draft vessels which opt to remain or are forced to remain in port, a small number of secure anchorages in Man-Of-War Harbor or secure berths in the basin at Truman Annex are available. Smaller craft have the choice of several havens and anchorages. Guidance on the choice of haven according to the direction of approach of the threat is given in the text.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Key West lies at the western end of a 125 mile chain of keys or low islands which extends southwestward from the southeastern tip of mainland Florida. The Keys are linked by the Overseas Highway whose bridges and causeways straddle the numerous gaps in the chain.

The average elevation of the Florida Keys is 5 feet above mean sea level. Key West is mostly 6 to 8 feet in the east, rising in the west to a plateau on the site of the old town of 12 to 18 feet.

The surrounding underwater topography is dominated by the shallow reef extending to between 5 and 10 miles either side of the chain of keys. To the south, the reef terminates abruptly where the ocean floor plunges to form the northern boundary of the Straits of Florida. To the north, the reef is both

This hurricane haven evaluation was prepared by LT CDR R.J.B. Turpin, RN, Royal Navy Exchange Officer at NAVENVPREDRSCHFAC.

wider and shallower, and shelves only slowly towards the shallow eastern waters of the Gulf of Mexico. Some shelter exists in the shallow waters of the reef to the north of the main keys. This is provided by a broken line of sand flats and mangrove-covered, uninhabited keys which lie parallel to the main keys and approximately 4 miles to the north. For further details see Chart 11442 Florida Keys - Sombrero Key to Sand Key and Chart 11434 Florida Keys - Sombrero Key to Dry Tortugas.

2. THE HARBORS AND THEIR FACILITIES

2.1 BERTHS FOR DEEP-DRAFT VESSELS

Figure IV-1 shows the principal harbors in the Key West area. The status of the deep water facilities on the western shore of Key West has been affected by the decline in Navy usage of the port in the recent past, starting with excessing of the Naval Station at Fort Taylor (referred to locally as Truman Annex) in March 1974. This has produced a deterioration in the facilities offered by the port which is reflected in the following paragraphs. It should be emphasized that there is already some reversal of this trend and that many of the limitations described below may gradually be rectified.

Figure IV-2 provides details of the former Naval Station at Truman Annex -- currently awaiting redevelopment -- and the three "D" piers comprising the Naval Station Annex. Only the North Mole at Truman Annex is in regular use for berthing deep draft vessels including visiting Navy ships. The former submarine and repair piers inside the basin are currently used for berthing small craft and at the time of writing, the quays and mole were littered with impounded craft from the 1980 Cuban refugee incident. These would become a serious missile hazard in the event of destructive-force winds.

The Naval Station Annex is in operational use by both the Navy and Coast Guard. Navy piers D-1 and D-3 are used for berthing aviation fuel tankers and accommodating the growing Navy Hydrofoil Squadron respectively. Pier D-2 accommodates the Key West Coast Guard headquarters and provides berthing for its vessels.

Mallory wharf is currently restricted to 18 ft draft vessels and lies north of Truman Annex. Mallory Dock is not in a safe condition for use at time of writing.

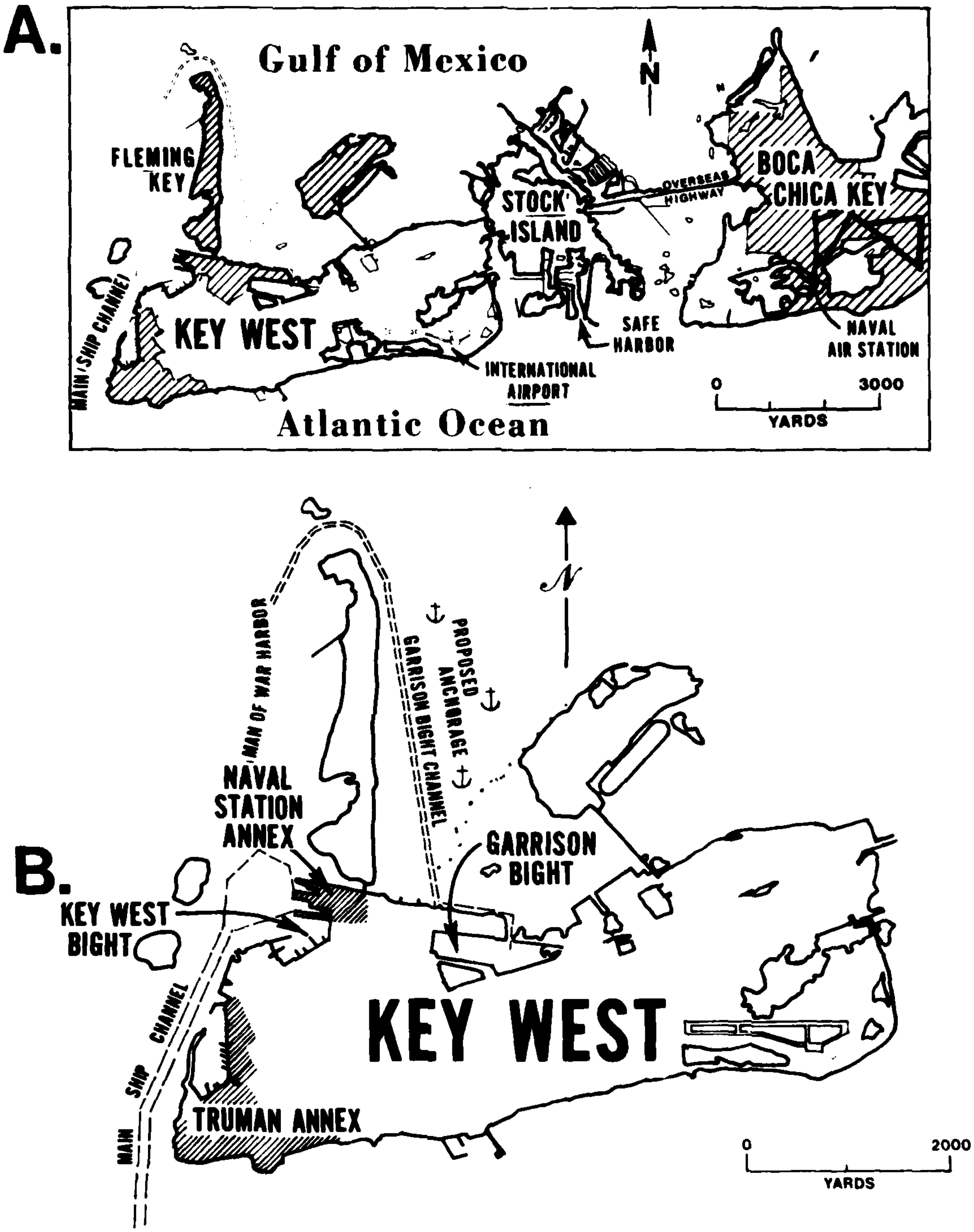

Figure IV-1. Locator maps of (A) Naval and other major facilities in the Key West area and (B) Principal havens of Key West.

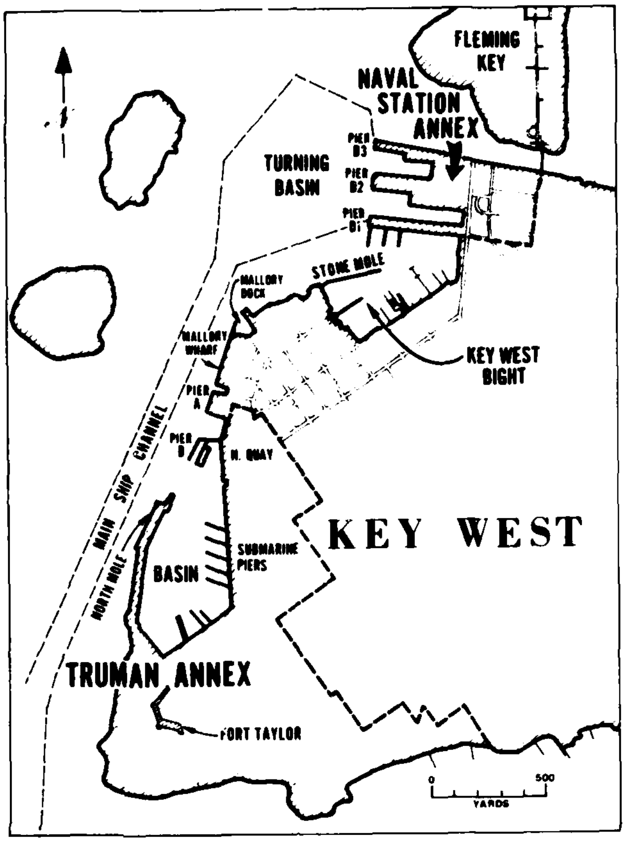

Figure IV-2. Berthing facilities adjoining the Main Ship Channel on the western shore of Key West.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

With the loss of a large salvage tug in November 1980, local tug assistance is currently limited to a 300 h.p. commercial tug and the Navy LCMs (small landing craft). Vessels requiring to change berth, anchor or sortie in the event of a tropical cyclone threat will therefore have to plan well ahead with such limited tug power, so that all moves can be completed before winds freshen. Larger tugs can be obtained from other ports, e.g., Miami. During the hurricane season, visiting Navy vessels should therefore order tugs appropriate to their size at least 2 weeks in advance of arrival.

Hurricane hawsers and fenders cannot be provided by the port. The designated anchorages on Chart 11447 - Key West Harbor, are not suitable for heavy weather use. Vessels of up to 20 ft draft should consider the use of the quarantine anchorage in Man-of-War Harbor for this purpose. No operational drydocks or heavy repair facilities for deep draft vessels are available.

Following the loss of the naval station infrastructure, no coordinated plan for the setting of hurricane conditions and preparation of Navy surface units for a hurricane threat exists. Instead, the remaining Navy and Coast Guard units have established separate plans. SOPA (Admin) is the Commanding Officer of the Naval Air Station at Boca Chica Key where detailed plans exist for the sheltering of personnel, the evacuation of aircraft and safeguard of Navy shore facilities. The Commander, Patrol Combatant Missile Hydrofoil Squadron Two has prepared contingency plans for tropical cyclone threats and should be consulted during the hurricane season (May through November) by visiting Navy surface units. Commercial ships should maintain liaison with both the Key West harbormaster and Commander, Coast Guard Group, Key West during a hurricane threat.

2.3 FACILITIES FOR SHALLOW DRAFT VESSELS

Commercial fishing fleets berth in Key West Bight to the south of the stone mole and also at the piers of "Safe Harbor" located on the southern shore of Stock Island (see Figure IV-1A). The channel approach to Safe Harbor is privately dredged to a least depth of 13 ft and also gives small tankers access to fuel bunkering facilities to the east of the harbor entrance.

At Key West charter boats and private recreational craft moor in Garrison Bight (Figure IV-1B) which comprises Municipal Marina to the west and Key West Yacht Club to the east. Anchoring is available in 6 ft at the Municipal Marina but the holding ground is not good. Anchoring or mooring elsewhere in Garrison Bight except in an emergency is not permitted. Additional berths for small craft may be available at Key West Bight or in the new recreational boat marinas to the east of Key West.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT KEY WEST

3.1 INTRODUCTION

In the following climatological analysis, the tropical cyclone threat at Key West is examined through the relationships between the cyclone's track, speed, intensity and seasonal factors. It is intended that the results of the analysis be used to supplement real-time forecasts in two ways:

(1) To provide a statistically-based extension of the threat warning out to 4 to 6 days.

(2) To focus attention on those storms likely to have the greatest impact on Key West.

The impact of tropical cyclones on the port has been judged from reported wind speeds together with the secondary effects of wave action and storm surge at the harbors and anchorages.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Key West is considered to have been a threat to the port. Similar studies in the Pacific Ocean have shown this radius to include the majority of tropical cyclones which have passed sufficiently close to produce operationally significant weather without burdening the analysis with countless insignificant events. The analysis concentrates on the period 1945 through 1979 for which hourly wind data are readily available. However, in order to improve the reliability of the "near pass probability" charts, the analysis period was extended back to 1886. Similarly, reference was made to earlier records of wind and flooding effects to determine whether such data supported the inferences drawn from the more complete records since 1945.

An average of 1.5 tropical cyclones per year have passed within 180 n mi of Key West for both the period 1886-1979 and 1945-1979. Figure IV-3 shows the seasonal variation in the frequency of these storms from 1945 through 1979. The July "break" in the hurricane season suggested in these data corresponds with the temporary cessation of a threat from storms moving towards Key West from the west Caribbean. July also marks the beginning of tropical cyclone formation in the tropical Atlantic but storms from this area do not appear to affect Key West until August. This relative "immunity" of Key West during July was further investigated by extending the search back to 1886, whereupon only one tropical cyclone was found to have produced significant effects during this month.

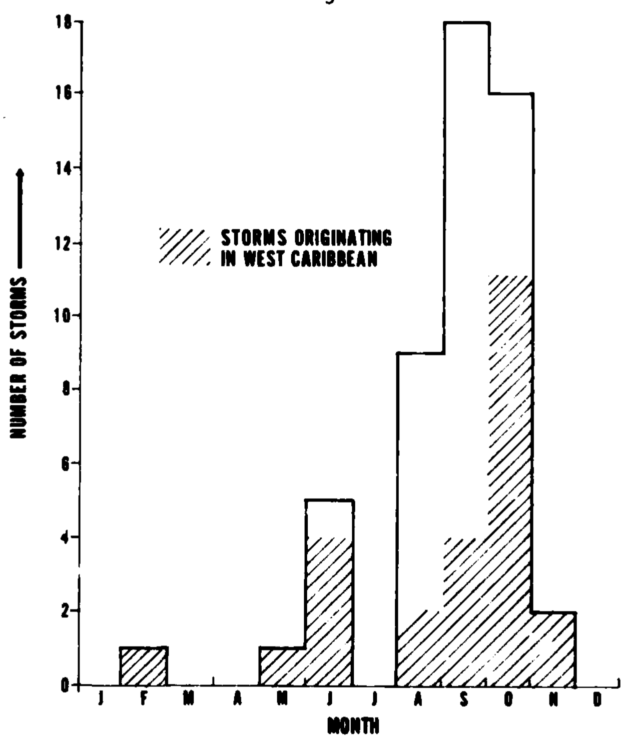

Figure IV-3. Seasonal variations in frequency of tropical cyclones passing within 180 n mi of Key West, 1945-1979. Note the July "break" in the season, and the changing contribution of threat storms which originated in the west Caribbean.

Resumption of the threat to Key West in August occurs as those storms originating in the tropical Atlantic east of the Antilles, display an increasing tendency to enter the Gulf of Mexico via Cuba or the Florida Straits instead of recurving north of the Bahamas. September sees a continuation of this trend into the peak of the season, but by October, the principal source of threat storms at Key West has reverted to those originating in the west Caribbean which subsequently move north across Cuba.

This systematic evolution of the tropical cyclone threat through the season at Key West is strongly reflected in the set of "near pass probability" charts of Figures IV-4 through IV-8. Each chart shows the probability of a tropical cyclone passing within 180 n mi of Key West calculated at a grid spacing of three degrees of latitude, together with the mean time for storms to reach their closest point of approach (CPA) to Key West.

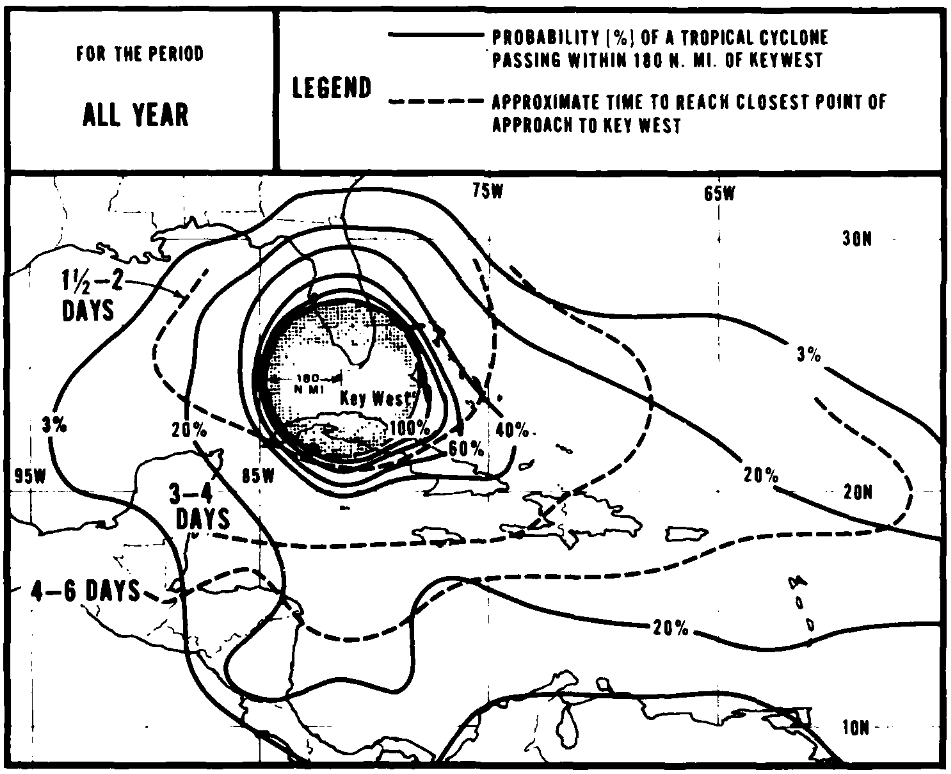

Figure IV-4. Annual probability that a tropical cyclone will pass within 180 n mi of Key West (based on data from 1871-1979). These combined data imply a dual threat to Key West: one from the west Caribbean and the other from the tropical North Atlantic, with a tendency for the west Caribbean storms to move more slowly. There is appreciable seasonal variation in both predominant source area and average speed of storms (see Figures IV-5 through IV-9).

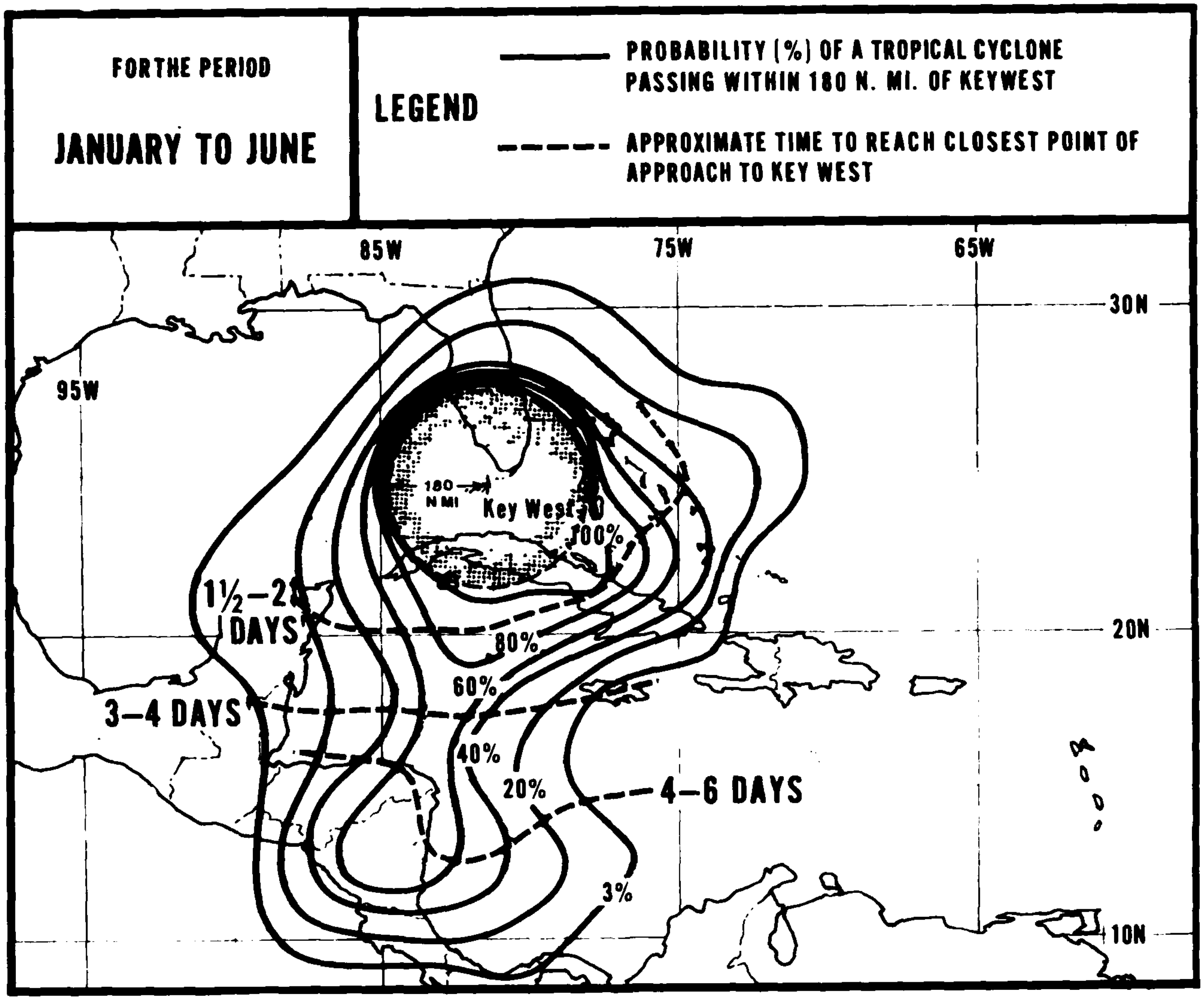

Figure IV-5. Probability that a tropical cyclone will pass within 180 n mi of Key West during the months January-June (based on data from 1871-1979). Before the July "break" in the season, the predominant threat to Key West is from storms which form in the west Caribbean Sea and subsequently move northward at a mean speed of 8 kt.

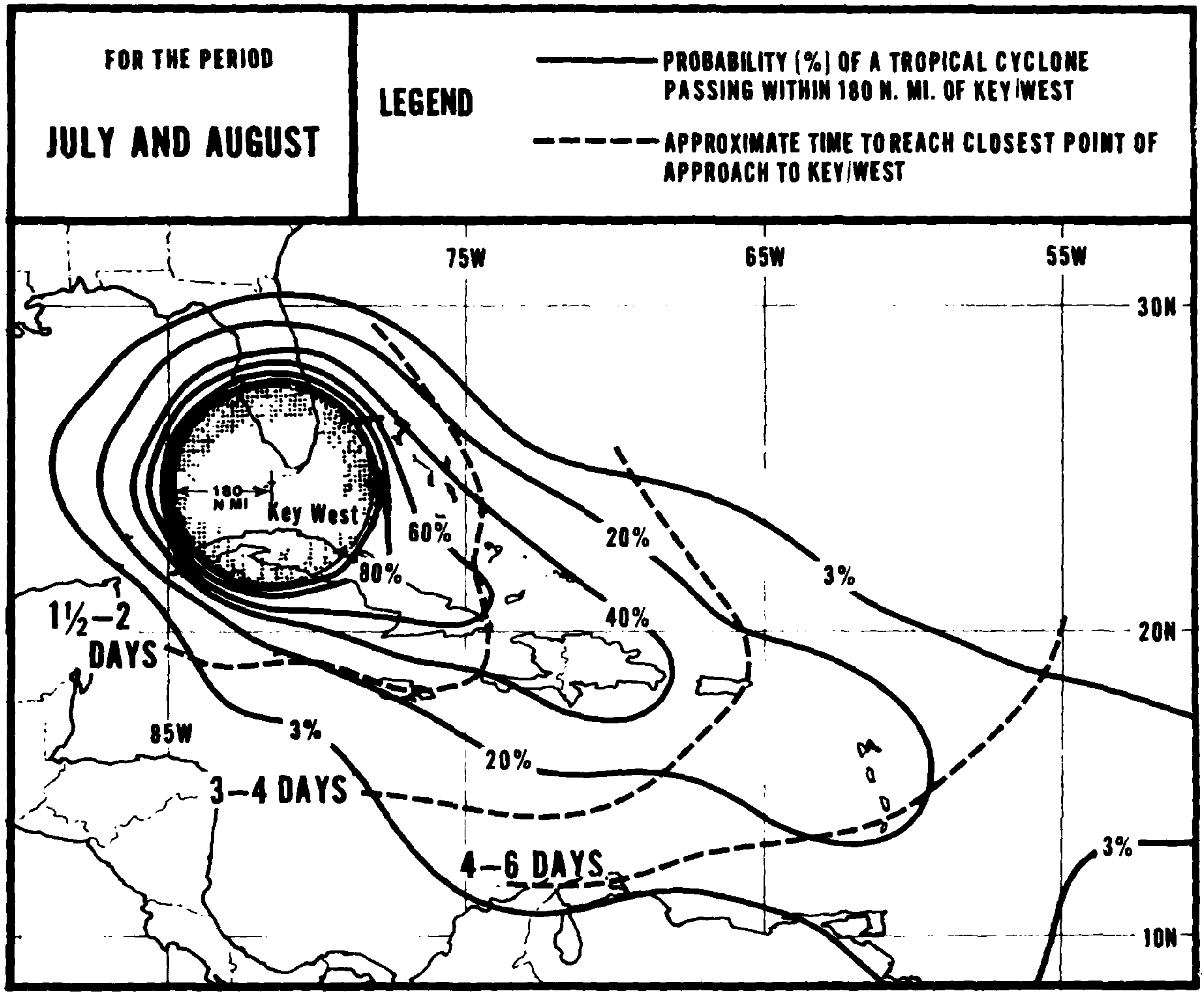

Figure IV-6. Probability that a tropical cyclone will pass within 180 n mi of Key West during July and August (based on data from 1871-1979). After the July "break," the predominant threat to Key West switches to storms that form in the tropical North Atlantic Ocean and move WNW at a mean speed of 15 kt.

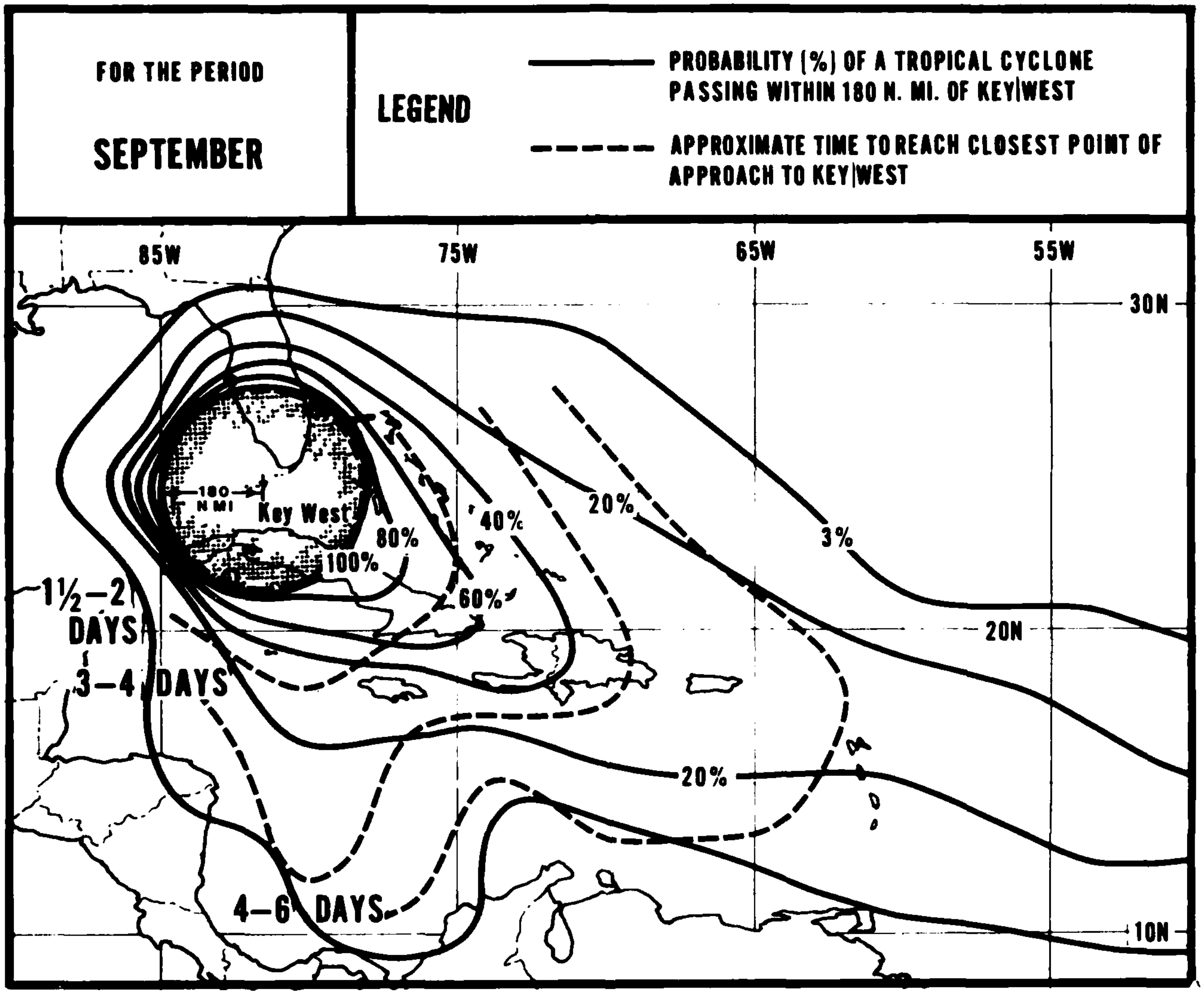

Figure IV-7. Probability that a tropical cyclone will pass within 180 n mi of Key West during September (based on data from 1871-1979). The predominant threat from tropical North Atlantic storms continues into September, but a threat from west Caribbean storms reappears; mean speed of threat storms originating in both areas is 11 kt.

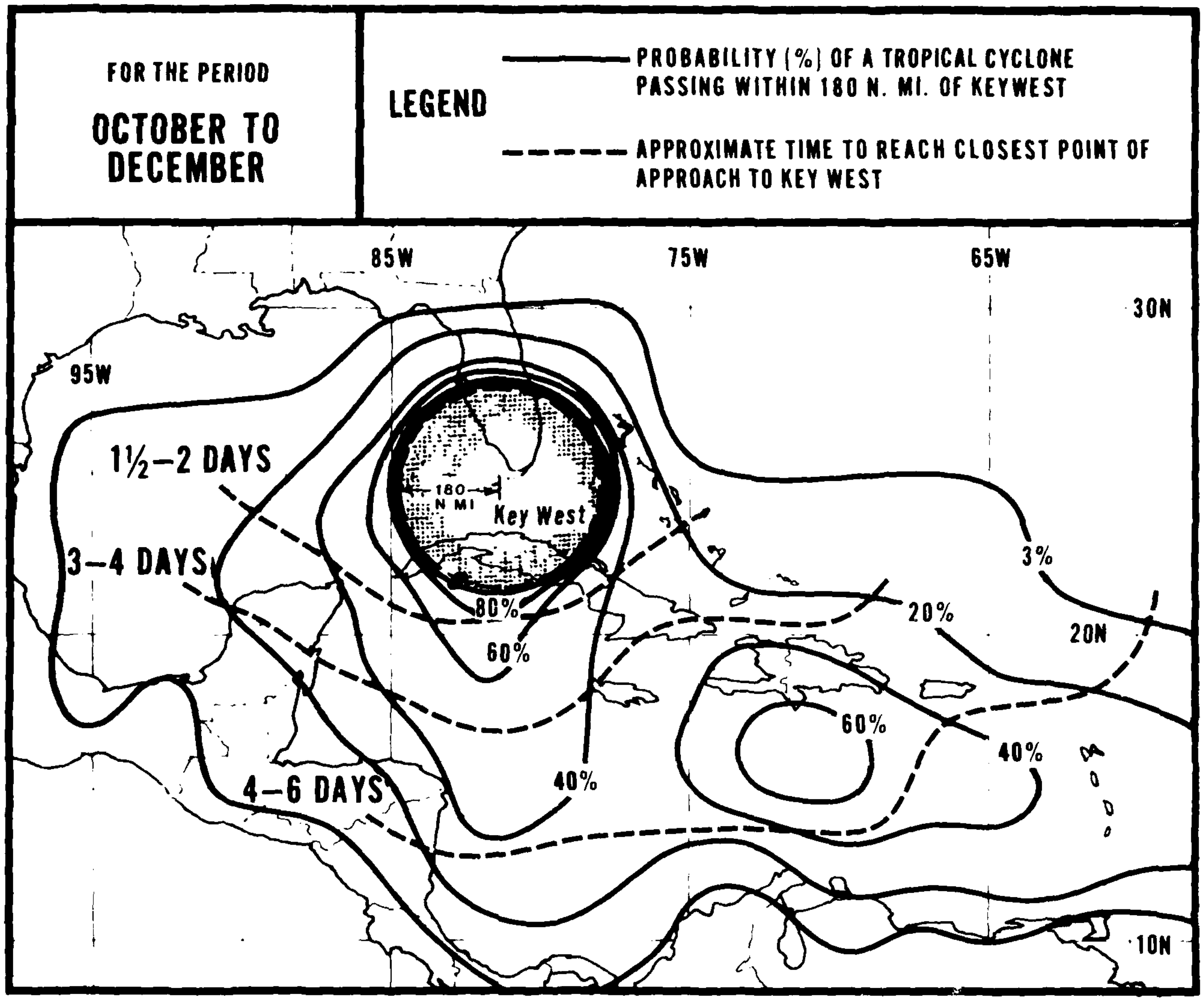

Figure IV-8. Probability that a tropical cyclone will pass within 180 n mi of Key West during the months October-December (based on data from 1871-1979,. By October, the predominant threat to Key West is from west Caribbean storms that either form in the area or enter the area from further east. The mean speed of storms moving northward from the west Caribbean during these months is 9 kt. (Note the isolated "pool" of high probability in the east Caribbean; this arises from the divergence of storm tracks to the west of this area.)

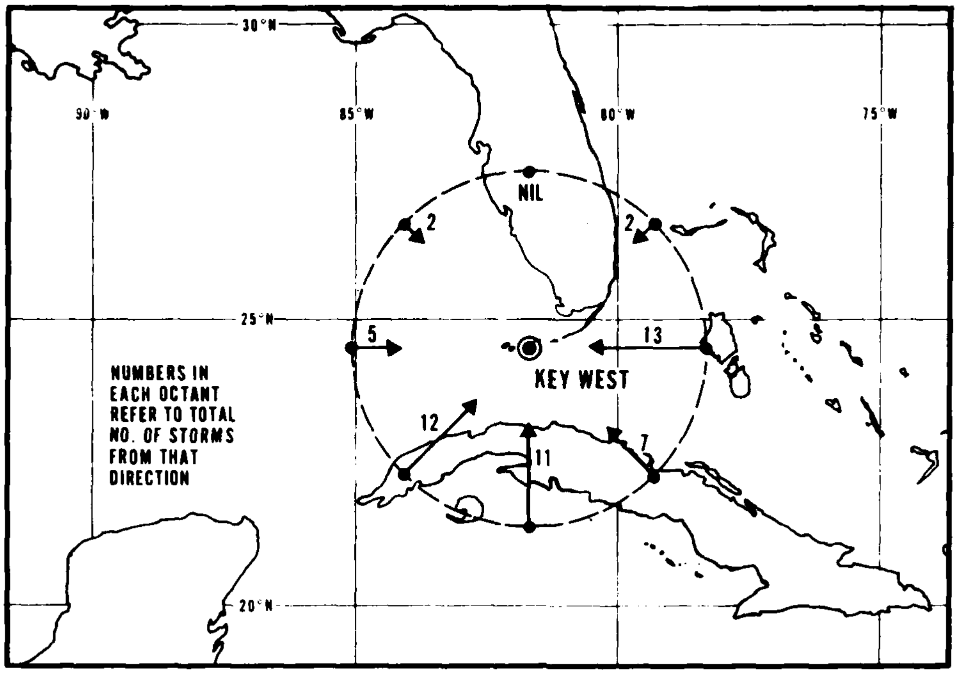

Figure IV-9. Direction of approach of tropical cyclones passing within 180 n mi [radius of circle above] of Key West during the period 1945-1979, determined at point of entry into the circle.

The direction of approach of threat storms determined at a 180 n mi radius is divided into octants in Figure IV-9. The predominant SSW direction is associated with the early and late-season tropical cyclones moving north from the west Caribbean. Those entering from the SE and E have mostly originated during the peak of the season in the tropical Atlantic east of the Caribbean Sea -- the storms entering the 180 n mi radius in the E octant having followed or moved north of the Antilles chain while those entering the SE octant have traversed the Caribbean.

3.2.1 Winds During Near Passes of Tropical Cyclones at Key West

Topographical shelter at the harbors and anchorages of Key West is negligible and winds at these locations would be close to those used in this section which were obtained from the International Airport and the Naval Air Station (Figure IV-1A). The following analysis concentrates on relating the impact of tropical cyclones in terms of wind strength at Key West, to the seasonal effects outlined in the previous section.

Figure IV-10 reproduces the seasonal histogram of threat storms with the addition of maximum wind speeds (kt) recorded at Key West for each of the 52 tropical cyclones affecting the port between 1945 and 1979. Maximum winds for each storm appear in the monthly columns in descending order of wind speed. For example, the 5 tropical cyclones affecting Key West between 1945 and 1979 in June, produced maximum winds of 50, 32, 26, 25 and 18 kt, respectively. The July "break" in the season referred to earlier, extends back to 1886 to the extent that the maximum wind at Key West in this month exceeded 20 kt on only one occasion, i.e., 29 July 1936 when a tropical cyclone passed within 55 n mi to generate an estimated maximum wind of 30 kt. The resumption of the threat in August is represented here by 9 relatively weak events followed by a number of devastating storms in September and October.

The relationship between direction of approach of the storm and maximum winds produced at Key West inferred by Figure IV-11, is that storms crossing Cuba from the Caribbean (octants SE, S and SW) present a greater threat than those approaching directly from the Atlantic (octants E and NE). Little threat is presented by Gulf of Mexico storms in the octants west through north.

A combined relationship between season, direction of approach and maximum winds at Key West is implied in Figure IV-12. Here, detailed information is restricted to storms producing winds of 34 kt or more at Key West. It is noteworthy that the seasonal evolution of the direction of approach of storms producing destructive-force winds from 1945 to 1979 follows the pattern of "near-pass probability" from 1886 to 1979 (Figures IV-4 through IV-8). Figure IV-12 implies that the principal threat of destructive-force winds is from storms originating in the west Caribbean which subsequently move northwards across Cuba in June, September and October. This is compounded in September, and to a lesser extent, in October by an additional threat from storms originating in the tropical Atlantic. The latter are usually more intense when approaching Key West to the south of the Antilles chain, i.e., through the Caribbean Sea.

(Figures IV-10, -11, -12 on following pages)

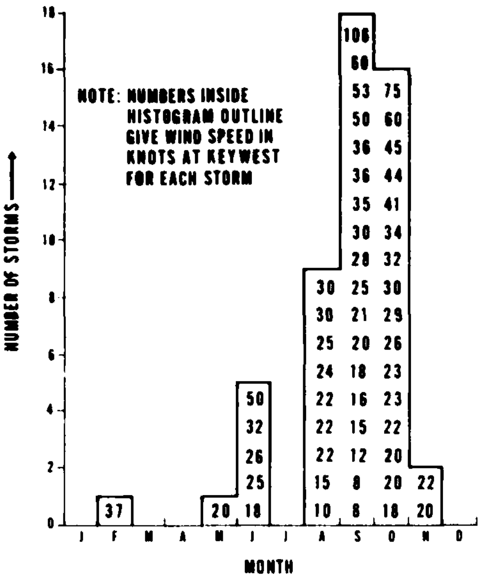

Figure IV-10. Seasonal variation in frequency of tropical cyclones passing within 180 n mi of Key West during the period 1945-1979 (as in Figure IV-3), showing maximum winds in kt recorded at Key West for each of the 52 storms appearing in the histogram outline. Except in August, the strongest winds at Key West have been associated with storms that originated in the west Caribbean.

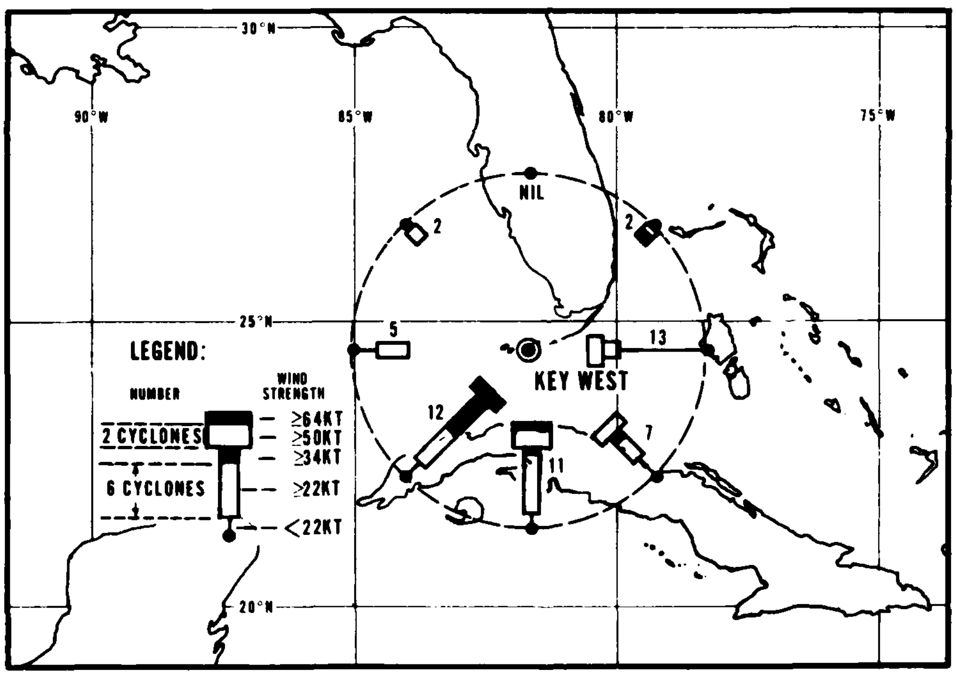

Figure IV-11. Relationship between tropical cyclones' direction of approach toward Key West and maximum winds recorded during passage, during the period 1945-1979. (The overall length of each symbol indicates number of storms approaching from each octant [shown by arrows in Figure IV-9]; symbol width and shading indicate maximum wind speed recorded at Key West for each storm, according to the Legend.)

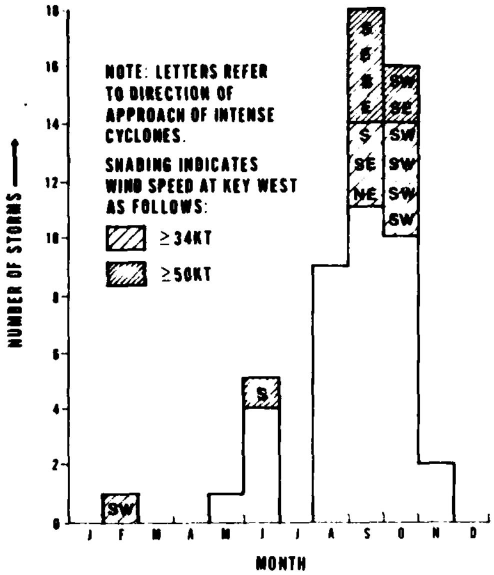

Figure IV-12. Seasonal variation in frequency of intense tropical cyclones passing within 180 n mi of Key West, showing relationship of direction of approach, maximum wind speed recorded at Key West, and time of year, for the period 1945-1979. (Storms approaching from SW and S octants originated in west Caribbean; others shown [approaching from SE,.E, NE] originated in tropical North Atlantic.

The complete tracks of tropical cyclones producing winds of 34 kt or more at Key West from 1945 to 1979 in Figure IV-13 provide an illustration of the principal directions of approach and sources of threat storms at Key West.

In a summary of the more dramatic storms affecting the Florida Keys by Dubrish (1980), which reaches back to the 16th century, hurricanes crossing Cuba from the Caribbean in the months of September and October predominate. In conjunction with the more recent data, Dubrish's summary implies a frequency of hurricane force winds (64 kt or greater) at Key West of once every 15 years and a frequency of destructive force winds (50 kt or greater) of once every 5 years. These figures warn against taking comfort from the quiet decade of the 1970's -- there have been many quiet decades before.

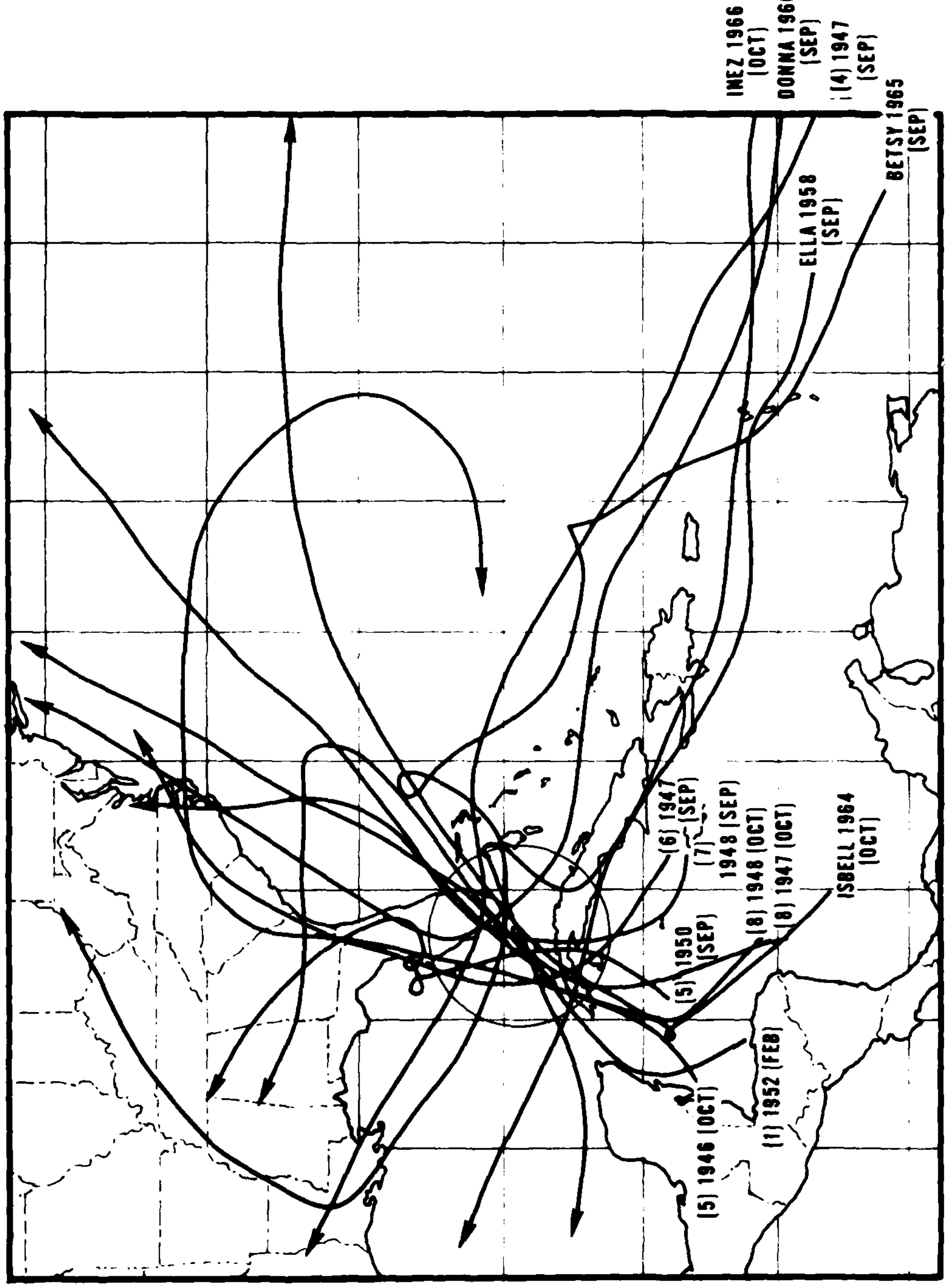

Figure IV-13. Complete tracks of the 13 tropical cyclones during the period 1945-1979 that caused winds of 34 kt or greater at Key West. Note the clear polarization of two threat source areas, west Caribbean and tropical North Atlantic; in terms of winds alone, storms originating in the west Caribbean have had the greater impact at Key West.

3.2.2 Wave Action

Apart from the protection from wave action provided by the Keys themselves and the man-made defenses added to them, the surrounding reef also exercises control over wave action. This control depends upon interaction between surface waves and the sea bottom and is therefore most effective in the shallow waters to the north of Key West (see Chart 11442). The line of shoals to the north of Key West also presents an effective barrier to ocean swells from the Gulf of Mexico except in the northwest channel. The reef and shoals to the south offer little protection from wave action.

There are two meteorological factors to consider: the probable ocean swell direction and the wind-wave direction. As the predominant swell issues ahead of advancing tropical cyclones, an indication of the direction of heavy hurricane swells at Key West can be obtained from the appropriate storm track data. Climatological preferences in the direction of approach of the more intense storms (see Figure IV-11) infer a probable heavy swell direction of between south and southwest. Wind direction and hence, wind-wave direction during the near-pass or strike of tropical cyclones is much more variable, depending not only on the direction of approach of the storm but also its passing side and CPA. Nevertheless, during the period 1945-1979, Figures IV-14 and IV-15 show a strong preponderance of winds above gale force from between SE and S. The two instances of hurricane force winds (both in 1948) were in the sector NE through N to NW and were produced by hurricanes passing close to the east of Key West.

This combination of shelter from wave action and climatological factors leads to the general conclusion that whereas the reef and shoals to the north of Key West provide good shelter from the occasional threat of wave action in that quadrant, there is little natural protection from the more commonplace threat of heavy ocean swell and wind waves from the southerly quadrant. A more specific assessment of wave action at each harbor is as follows:

(1) Deep Water Berths

(a) Truman Annex and Mallory Wharf (Figure IV-2). Deep water berths outside of the North Mole, Piers A and B and Mallory Wharf are badly exposed to ocean swells from the southwest associated with storms moving up from the west Caribbean. Berths in the basin at Truman Annex are well protected from wave action.

(b) Naval Station Annex - 'D' Piers (Figure IV-2). Waves generated in Man-of-War Harbor by northerly winds will affect the piers (D-3 in particular) where seas of 3 ft have been experienced. These conditions can arise both during winter cold outbreaks and the hurricane season.

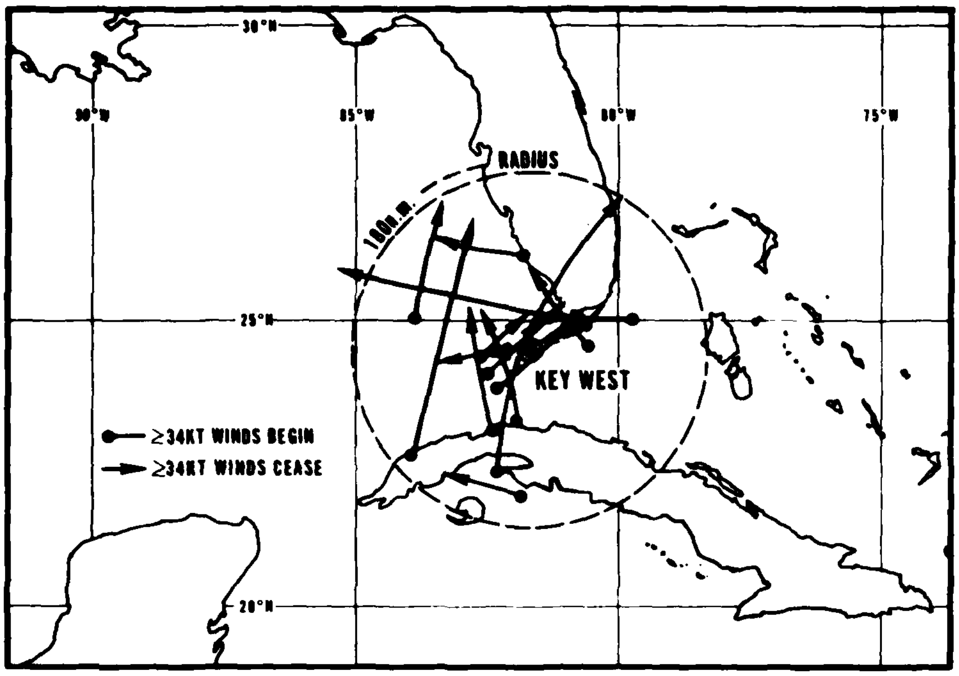

Figure IV-14. Track segments of 1945-1979 tropical cyclones showing storm positions when winds of 34 kt or greater were recorded at Key West. Some bias in direction of movement and passing side is evident during the period; this has produced the predominance of southerly winds depicted in Figure IV-15 below.

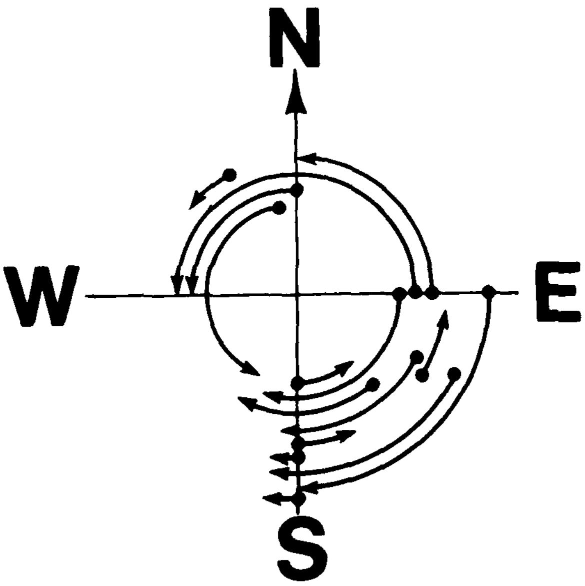

Figure IV-15. Direction of winds 34 kt or greater at Key West during near passage of tropical cyclones 1945-1979, with symbols for beginning and ending of gale force winds as shown above in Figure IV-14. Wind direction changes clockwise/counterclockwise according to passing side of storm: for storms moving south to north, changes are clockwise during storm passage to the west and counterclockwise during passage to the east. (Two of the latter storms produced hurricane force northerly winds.)

(c) Man-of-War Harbor - Anchorage (Figures IV-1B and IV-16). Sheltered from sea and swell by the shallow reef north of the turning basin. Waves generated within the anchorage are unlikely to affect vessels with an anchor cable scope appropriate to hurricane conditions.

(2) Berths for Shallow Draft Vessels (Figure IV-2)

(a) Key West Bight. With the addition of the stone mole, shelter from wave action from all directions is provided.

(b) Safe Harbor, Stock Island (Figure IV-1A). Sea and swell from the southern quadrant will cause heavy surf at the harbor entrance and during southerly winds a seiche of 2 to 3 ft inside the harbor is possible. These conditions are likely to be associated with flooding due to wave run-up and storm surge (Section 3.2.3) from Caribbean storms passing close to the west of Key West. Such an increase in sea level would advance the effects of sea and swell further northwards into the harbor.

(c) Garrison Bight (Figure IV-1B). Protected from wave action from all quarters. The possibility of moderate storm surge (3-4 ft in hurricane force northerly winds - see Section 3.2.3) will require lines to be tended.

3.2.3 Storm Surge and Tides

The increase in water level known as "storm surge" can be characterized in the Northern Hemisphere as a moving dome of raised water centered just to the right of the storm's center. Its height depends on two groups of factors; the first relates to the storm's intensity and movement; the second relates to water depth and the shape of the bottom. The worst combination of circumstances (Harris, 1963) would include the following:

(1) Intense storm approaching perpendicularly to the coast at a high speed of advance.

(2) Broad, shallow, slowly shelving underwater topography.

(3) Landfall within 30 miles to the left (looking ahead of the storm towards the coast) of the port at risk.

(4) Coincidence of storm surge with high astronomical tide.

At Key West, the second factor (underwater topography) would imply a greater threat of storm surge from tropical cyclones approaching from the Gulf of Mexico. However, the preceding climatology indicates that tropical disturbances from this direction (north) are both rare and of low intensity and instead, the above criteria are best met by the intense storms approaching Key West from the west Caribbean and passing close to the west. There are three occasions this century (September 25, 1909, October 17, 1910, and October 18, 1944) when streets of the Old Town (greater than 10 ft above MSL) have been flooded by storms moving along this track. Fortunately, the infamous Labor Day

Hurricane of September 2, 1935, crossed the Keys well to the east of Key West and, despite northerly winds far exceeding hurricane force at Key West, flooding was characteristically concentrated at, and to the right of the landfall. Two further cases of northerly winds well above hurricane force in 1948 from storms crossing the Keys to the east failed to produce serious flooding at Key West but an increase in water level of 3 to 4 ft was produced in Garrison Bight and the North Shore. Tropical cyclones approaching Key West from the east will not produce serious flooding unless they pass close to the south of the line of main Keys. The strip of shallow water to the south is so narrow that on only one occasion has a storm from this quadrant produced significant flooding, i.e., 10 September 1919 when Cow Key to the east of Key West showed evidence of flooding to 14 ft above MSL.

Thus, the principal storm surge threat at Key West is presented by tropical cyclones moving north from the west Caribbean which pass to the west of the island. The height of surge to be expected will appear in the hurricane warning issued by the National Weather Service. However, the large variability in surge heights along the Florida Keys due to their "leakiness" and the added effects of wave run-up and astronomical tides should be noted in interpreting surge height forecasts. Generally, shores adjacent to the deeper channels or sheltered from wave action, will experience lower water levels than elsewhere. The smooth storm surge profile for the Keys (U.S. Army Corps of Engineers, 1972) gives a height of 8 ft at Key West for the "100-year Intermediate Regional Hurricane." The effects of astronomical tides and wave run-up must be added to this figure before making comparisons with the reports of serious flooding in the old town earlier this century. Such reports show that these combined effects can lead to water levels at Key West as high as 15 ft above MSL in a 100-year period.

Astronomical tides at Key West have mean and maximum ranges of 1.8 and 3.0 ft, respectively. Cautions to be observed in regard to tidal currents appear in Figure IV-16. These effects will be considerably magnified by the wind and surge effects created by a tropical cyclone.

4. THE DECISION TO EVADE OR REMAIN IN PORT

4.1 THREAT ASSESSMENT

For the masters of deep draft vessels, the current shortages of tug power, protected alongside berths and hurricane anchorages at Key West makes an early assessment of the threat posed by an individual tropical cyclone essential. This assessment and the related setting of Hurricane Conditions by Navy and Coast Guard and civil authorities is best achieved by using the real-time forecasts in conjunction with the foregoing climatology.

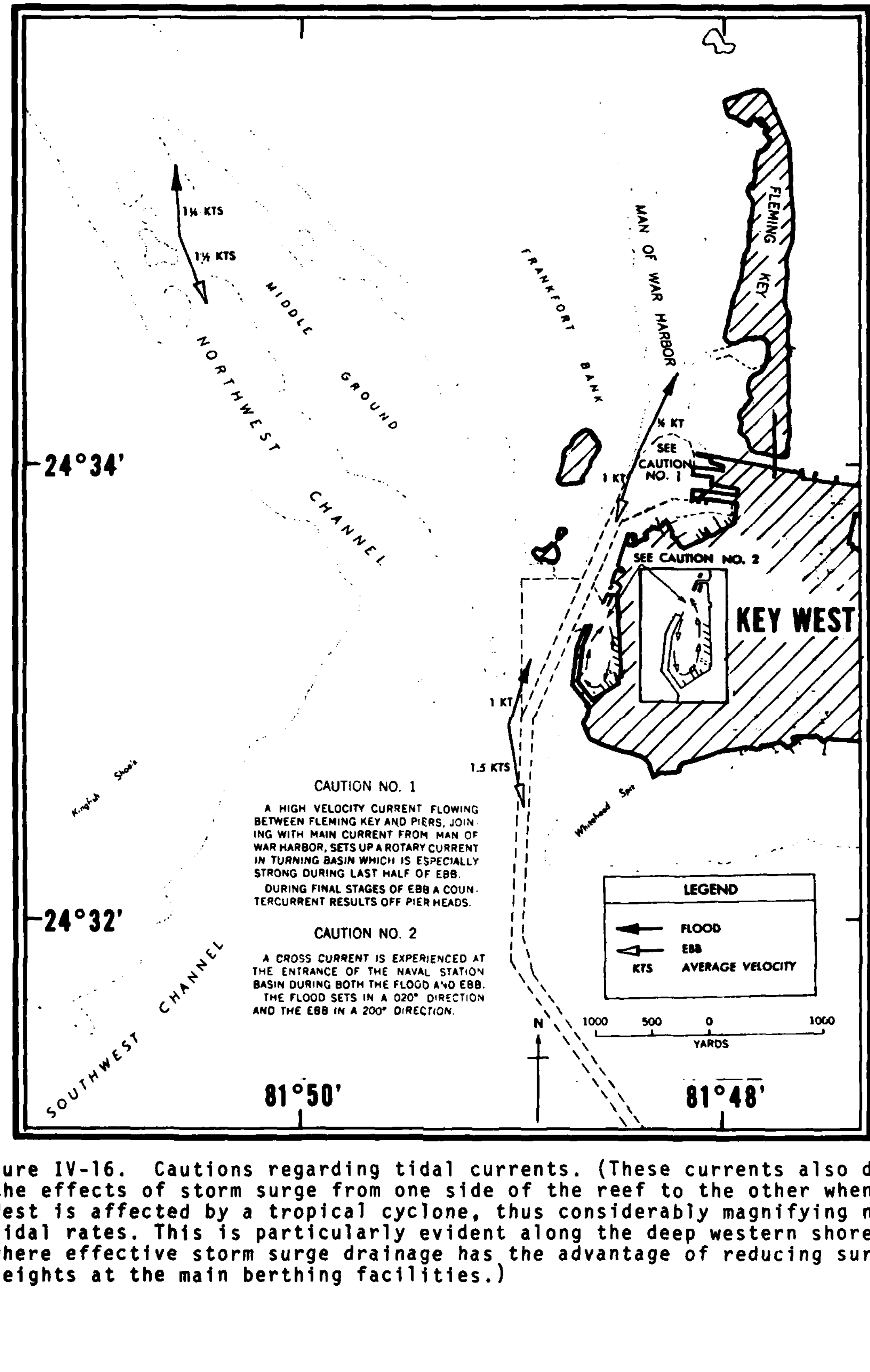

Figure IV-16. Cautions regarding tidal currents. (These currents also drain the effects of storm surge from one side of the reef to the other when Key West is affected by a tropical cyclone, thus considerably magnifying normal tidal rates. This is particularly evident along the deep western shores where effective storm surge drainage has the advantage of reducing surge heights at the main berthing facilities.)

A rationale for combining climatological and real-time forecast information for the setting of Hurricane Conditions is provided in the Appendix. This, however, only addresses the threat in terms of the timing of the onset of destructive force winds. The decision to sortie or remain in port must also consider the effects of wave action and storm surge. These effects depend not only upon expected wind speed but also upon the direction of approach and the forecast passing side of the storm. They can be summarized as follows:

(1) In terms of their frequency, intensity and the combined effects of wind, sea, swell and storm surge; the greatest threat is presented by tropical cyclones moving northwards toward Key West from the west Caribbean. For brevity, these storms are referred to later as "West Caribbean Storms."

(2) Although the effects of "West Caribbean Storms" will be much reduced if the center passes to the east of the island, forecast errors will not always allow this factor to enter into the decision to sortie until it is too late for effective evasion at sea.

(3) A secondary threat is posed by storms originating in the tropical Atlantic. For a particular storm intensity, their impact on Key West in terms of sea, swell and storm surge is less than for "West Caribbean Storms."

(4) Key West experiences little effect from tropical cyclones in the Gulf of Mexico or from tropical depressions forming within 180 n mi of the port. Furthermore, minimal threat exists from any quarter during the "July break" in the season. The maximum threat of damage from tropical cyclones to vessels at the port occurs in early October.

4.2 EVASION AT SEA

Under the present circumstances at the port, evasion at sea is the recommended course of action for all seaworthy deep draft vessels capable of making 15 kt or more when the port is under threat from an intense tropical cyclone or hurricane. The secondary effects of wave action and storm surge depend upon the direction of approach and expected passing side of the storm as well as its intensity and the expected wind speed. Each threat must be judged on its merits but the following guidelines embody these additional considerations:

A decision to sortie is recommended when:

(1) Winds of 40 kt or greater are expected from storms approaching Key West from the south or southwest (i.e., "West Caribbean Storms") which are forecast to pass close (within 50 n mi) to the island or within 100 n mi to the west of the island. An early decision to sortie is especially important in these circumstances because the effects of southerly winds on pilotage and towing in the harbor and its approaches may be felt well ahead of the storm.

(2) Winds of 50 kt or greater are expected from "West Caribbean Storms" which are forecast to pass clear (more than 50 n mi) to the east of the island.

(3) Winds of 64 kt or greater are expected from storms approaching from the east or southeast (typically, storms originating in the tropical Atlantic).

4.2.2 Evasion Plans and Tactics

Evasion tactics at sea on leaving Key West are constrained by offshore shoals and islands, particularly to the south and east. If these navigational restrictions preclude early crossing of the storm's expected track to the "safe" semicircle and beyond, evasion routes leading broadly ahead of the storm towards open ocean are preferable. Using these principles and bearing in mind the uncertainties in the forecast track of a storm, the recommended routes and the timing of the preparations for, and execution of sortie for the three threat situations outlined above, are as follows:

(1) "West Caribbean" storms forecast to pass close to the island or clear to the west. Full preparations for sortie should be made at the setting of Hurricane Condition III. After an early departure (at or before the setting of Hurricane Condition II) to avoid the possibility of pilot and tug operations being hampered by southerly winds, slower vessels should proceed northeastwards through the Florida Straits with a later option to use the NW Providence Channel or continue northwards to the open ocean. Navy units with operational requirements to stay in the Gulf of Mexico or Caribbean area and other ships with the necessary speed capability may attempt to cross ahead of the threat by sailing early westwards at best speed. Given the necessary local navigational knowledge this operational objective could more safely be met by an eastward evasion via the Old Bahama Channel then southward to the Caribbean via windward passage.

(2) "West Caribbean" storms forecast to pass clear to the east of the island. Forecast uncertainties demand that preparations for sortie be made as for (1) above. If at the setting of Hurricane Condition II, a clear pass to the east is still indicated, a relatively late sortie westward towards the Gulf of Mexico, with the possibility of an early return to Key West is feasible. Without such assurance, immediate departure eastwards according to the recommendations at (1) above should be executed.

(3) "Tropical Atlantic" storms approaching from the east or southeast. Forecast tracks for these storms carry considerable uncertainty related to the possibility of stalling, looping or late recurvature. The consequences are twofold:

(a) The evasion route to the Atlantic via the Florida Straits carries the danger of encountering storms forecast to continue westwards into the Gulf but which recurve late instead.

(b) These special difficulties in assessing the threat at Key West from storms approaching from the east or southeast will probably lead to a late decision to sortie. This is especially likely in the case of storms which loop or stall just east of the Bahamas and subsequently move toward Key West.

Full preparations for sortie or reberthing should be completed at the setting of Condition II and executed at the setting of Condition I. The recommended evasion route is westward ahead of the storm then south through the Yucatan Channel to cross ahead of the threat.

(4) Special Options. The exceptional speed and fragility of the Navy hydrofoil craft[1] and their specialized requirements for logistic support lead to a different rationale for both the decision to sortie and subsequent evasion tactics.

4.3 RETURNING TO HARBOR

The aftermath of a tropical cyclone strike at the port may include new navigational hazards such as wrecks in the channels and displaced navigational markers. Check with the harbor authorities before attempting to return.

4.4 REMAINING AT KEY WEST

In the event of a tropical cyclone threat which according to the guidelines in Sections 4.1 and 4.2, merits sortieing from the port, some reberthing of disabled vessels or other vessels unable to evade at sea will be necessary. The timing of preparations for reberthing should observe the recommendations of Section 4.2.2. The properties of the alternative deep water berths and anchorages available are summarized below:

(1) Man-of-War Harbor (Figures IV-1B and IV-16). A hurricane anchorage of proven worth[2] suitable for vessels with serviceable main machinery and capability to deploy both anchors.

(2) Naval Station Annex "D" Piers (Figure IV-2). The inside berths at the finger piers 1 through 3, south of Pier D1 provide adequate shelter for small craft. Larger vessels at the "D" piers if unable to sortie, should anchor in Man-of-War Harbor or seek shelter in the basin at Truman Annex.

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[1]See Commander Patrol Combatant Missile Hydrofoil Squadron Two INSTRUCTION 3140.1.

[2]Navy buoy tender IVY (1100 tons) rode out effects of the 1935 Labor Day Storm here at two anchors. Preparations to steam at anchor made but not employed.

(3) Truman Annex and Mallory Wharf (Figure IV-2). The basin in Truman Annex has the potential for providing many sheltered berths for vessels up to 30 ft draft (Crusoe, 1980). Currently there is a serious missile hazard and a shortage of strong points for securing. A survey of the former submarine piers would be required before use by vessels other than small craft.

Some secure berths are available between the North Quay Wall and Pier B and also inside the North Mole. Any vessels at the berths outside the basin -- on the Mole, Piers A and B or Mallory Wharf -- require reberthing.

The proximity of the basin to the deep channels connecting the Atlantic and Gulf of Mexico sides of the reef provides for good drainange of storm surge either to the north or south. This is responsible for accelerating the currents illustrated in Figure IV-16 and reducing the surge heights within the basin and hence the risk of vessels riding over quays or piers.

4.5 RUNNING FOR SHELTER

Ships at sea threatened by tropical storms during July may, with due regard to current forecasts, consider running for shelter to Key West which has proved to be a safe haven during this period of the hurricane season (see Section 3.2.1).

5. ADVICE TO SHALLOW DRAFT VESSELS

Small recreational craft should, if possible, be removed from the water and firmly secured ashore when a hurricane watch is issued. The City of Key West Hurricane Contingency Plan (Veliz, 1980)[3] includes advice on securing vessels, but is mainly aimed at those already in possession of alongside berths. Anchored vessels should increase their anchor cable scope to 10:1 and if possible employ a second anchor 180° from the first.

The effects of hurricane conditions on the alternative berthing facilities and anchorages available are summarized below:

(1) Key West Bight (Figure IV-2). In terms of protection from sea, swell and storm surge, this is the best small vessel haven available irrespective of the direction of the threat. Minimizing your craft's exposure to northwesterly winds should be the main consideration in rigging lines and choice of berth.

(2) Safe Harbor, Stock Island (Figure IV-1A). In common with other berthing facilities on the southern shores of the lower Keys, there is a serious threat of flooding due to storm surge and wave run-up from storms moving north from the west Caribbean unless they pass clear to the east. Storms approaching from the east can produce similar flooding if they pass close to the south of

[3]Copies available from the City Dockmaster (294-3721, Ext. 167).

the Keys. The increase in sea level also advances the destructive effect of wave action further inshore. Under most circumstances therefore, vessels normally berthed in this harbor and others along the southern shore, should be prepared to seek alternative shelter in the event of a hurricane threat especially from storms moving toward Key West from the Caribbean.

(3) Garrison Bight (Figure IV-1B). Garrison Bight is well protected from sea and swell and offers some protection from winds, irrespective of threat direction. In common with other berthing facilities on the northern shore, some increase in water levels due to strong northerly winds may follow the near pass of a "West Caribbean" storm to the east of the island. The combination of poor holding ground and limited swinging room makes Garrison Bight a poor hurricane anchorage for vessels without alongside berths.

(4) Alternative Anchoring and Mooring Practices. Vessels unable to occupy the berths recommended above may, with foresight, be able to take advantage of the shelter offered by the reef to the north of the main Keys -- known locally as the "Backcountry". The following extract from the U.S. Coast Pilot 4 (1979), Cape Henry to Key West -- is relevant:

> "Hurricane Moorings - small boats should seek shelter in a small winding stream whose banks are lined with trees - preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of trees will act as fenders and the branches, having more give, will ease shocks in gusts. Keep clear of tall pines as they have shallow roots and are more apt to be blown down."

Fishing vessels possessing the necessary local navigational knowledge employ these methods among some of the uninhabited mangrove-covered keys to the north of Key West.

Owners of recreational craft may prefer the more accessible but less sheltered anchorage to the east of Fleming Key outside the inshore restricted areas. Chart 11441 - Key West Harbor and pproaches, indicates better holding ground to the east of Garrison Bight Channel than to the west (Figure IV-1B). Having laid suitable anchors with ample scope of cable, crews can regain the shore via the Navy boat landing on the east shore of Fleming Key (Chart 11447, Key West Harbor). Despite poor shelter from winds from north through northeast, hurricane force winds over such shallow water are estimated to produce seas of less than 3 ft (U.S. Army Coastal Engineering Research Center, 1973).

APPENDIX: PROPOSED RATIONALE FOR SETTING HURRICANE CONDITIONS AT KEY WEST

The setting of Hurricane Conditions is the established framework at Navy ports and air stations for formalizing the assessment of and planned reaction to the threat from approaching major cyclonic storms. In fact at Key West, Navy, Coast Guard and civil authorities all employ this principle in establishing their individual hurricane contingency plans (Commander, Patrol Combatant Missile Hydrofoil Squadron Two (1980); Department of the Navy, NAS Key West (1980); Department of Transportation, U.S. Coast Guard (1980); Veliz, F., City of Key West (1980)). These plans all follow the broad outline promulgated by the Department of the Navy, Office of the Chief of Naval Operations (1974) starting with the setting of Hurricane Condition IV for "a possible threat of destructive winds of force indicated within 72 hours" through to Hurricane Condition I when "destructive winds of force indicated are anticipated within 12 hours or less."

The following rationale for setting Hurricane Conditions at Key West is intended to make the best use of the foregoing climatological threat analysis and the real-time forecasts:

(1) Plot the position of all newly formed tropical or subtropical depressions from the Military/Marine/Aviation Hurricane Advisory (U.S. Dept. of Commerce, 1980) on a copy of the appropriate "Near-Pass Probability Chart" selected <u>according to time of year</u> from the series of Figures IV-5 through IV-8, then observe procedures (2), (3) or (4) below according to the initial range of the newly formed depression from Key West.

(2) <u>If the depression has formed within 180 n mi of Key West</u>, a potential threat of destructive force winds within 12 hours exists (Hurricane Condition I). However, climatological information indicates that such a threat is unlikely especially for depressions forming north of Cuba. Nevertheless, a plot of actual and forecast positions and corresponding wind radii should be maintained until the depression has dissipated or moved decisively away.

(3) <u>If the depression has formed within 360 n mi of Key West</u>, urgent assessment of the threat is required. Plot its forecast positions for 12 and 24 hours hence (and the extended outlook positions to 48 and 72 hours if available). Climatological information indicates that it is unlikely that tropical depressions formed within this radius will reach hurricane intensity at or near Key West unless they have formed within the west Caribbean. Serious consideration should be given to setting Hurricane Conditions III or II -- appropriate to the <u>earliest</u> estimated time of arrival at Key West (from

climatological data on the chart and the real-time forecast) -- for any tropical depression in the west Caribbean in September or October with a forecast movement towards the port. Similar action for depressions forming in other areas would require more positive indications in the real-time forecast of intensification and close encounter with Key West.

At a radius of 360 n mi or less, the climatological probability envelopes on the chart referring to entry into a circle of 180 n mi radius centered on the port, are of diminished value in assessing the threat. Nevertheless, they can be considered to reinforce a forecast threat from a tropical cyclone which moves inside or is forecast to move inside the 40% envelope. Further actual or forecast movement into the 60% and even the 80% envelopes can be regarded as continued reinforcement of the threat, as can a storm's alignment with, and subsequent movement along, a major seasonal threat trajectory (indicated by the direction of the major axes of the climatological probability envelopes).

However, it is unlikely that further regard will be paid to these envelopes after the tropical cyclone is within 48 hours of the port. The setting of Conditions III, II and I will depend more upon actual and forecast movement and wind radii.

(4) If the depression has formed beyond 360 n mi of Key West, a greater opportunity exists to examine the interaction between its actual and real-time forecast movement and the climatological probability envelopes before making a decision on the setting of Hurricane Conditions. Depressions formed outside 360 n mi may include those which have developed in the tropical North Atlantic Ocean outside the Caribbean Sea and beyond perhaps, the eastern limits of the "near-pass probability charts."

NO THREAT to Key West is considered to exist as long as any tropical cyclone lies beyond a radius of 360 n mi centered on the port, AND lies outside of:

(a) The 3% Climatological Probability Envelope, or

(b) the geographical limits of the apropriate "near-pass Probability chart."

THREAT ASSESSMENT should proceed as follows:

Examine the actual and forecast movement of the depression in relation to the climatological probability envelopes for the following indications of a reinforced threat:

(i) Movement towards increasing climatological probability (of passing within 180 n mi of Key West).

(ii) Alignment with and subsequent movement along a major seasonal threat trajectory (i.e., along the major axes of the probability envelopes).

The depression's progress should be continually reviewed in relation to the following specific milestones in threat escalation; these may not all arise during the approach of every threat storm, nor may they necessarily occur in the order listed:

A. Entry into the 3% climatological probability envelope. A measurable risk of weather effects from the cyclone now exists. Determine the estimated time for it to reach its closest point of approach to Key West by referring to the dashed lines on the chart.

B. Entry within the 4-6 day climatological time line. If cyclone lies within 3% probability envelope AND its forecast track lies toward the 20% envelope, set Hurricane Condition V ("possible threat of destructive winds of force indicated within 4-6 days").

C. Entry within the 3-4 day climatological time line. If cyclone lies within 20% probability envelope or is forecast to move inside this envelope within 24 hours, the setting of Hurricane Condition IV ("destructive winds of force indicated are possible within 72 hours") should be contemplated.

Further reinforcement for setting Condition IV given the above circumstances is provided by any combination of the following features:

(i) Actual or forecast MOVEMENT along a major seasonal threat axis.

(ii) Extended outlook MOVEMENT indicating a strike or close pass at Key West within 72 hours.

(iii) Actual or forecast development to storm or hurricane category.

(iv) Actual or forecast track via Caribbean Sea during September or October (climatologically favoring development).

D. Entry within a radius of 360 n mi centered on Key West. Tropical cyclones lying outside the 3% probability envelope should be scrutinized for signs of development and actual or forecast movement toward the port.

E. Entry to within 48 hours of the port according to earliest estimate from actual, forecast and climatological data. Actual or forecast movement of a cyclone in relation to the climatological probability envelopes at and above the 40% level and alignment of this movement with the main threat axes will indicate some reinforcement of threat. However, at this range these envelopes are of diminished value and the setting of conditions III, II, and I will depend principally on actual and forecast movement and wind radii alone.

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V: CONTENTS

V. MAYPORT, FLORIDA

SUMMARY

The conclusion reached by this study is in full agreement with the opinion held by Mayport and Jacksonville port authorities, both military and civil: ". . . Mayport Basin and the Port of Jacksonville are not to be considered a haven during hurricane conditions (forecast winds 64 kt or greater) . . ." The surrounding topography is low and does not provide an extensive wind break. Mayport Basin is in close proximity to the channel entrance from the open ocean. Consequently, little reduction of the coastal surge will occur in the basin, and some penetration of swell through and over the entrance jetty will occur.

A decision on a case-by-case basis is required for severe tropical storm (forecast winds 50-63 kt) conditions. Some units may be retained in the basin at Mayport if forecast winds are less than 60 kt. The Port of Jacksonville, which is less susceptible to storm surge, may be used as a haven from certain tropical storms. To remain in port under such conditions implies considerable confidence that the sustained wind speed will not exceed 60 kt.

It is the recommendation of this study that all U.S. Navy ships capable take action to evade at sea when a tropical cyclone exceeding or forecast to exceed hurricane force threatens Mayport or the Port of Jacksonville. The difference between 50 and 63 kt of local wind is extremely difficult to forecast, so caution must be exercised in applying predefined rules based on a difference of only 10 or 15 kt.

Special care should be exercised for tropical cyclones approaching from the southeast. These have the greatest potential for hazard to shipping at Mayport. Those storms which will pass over land are of lesser concern.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Figure V-1, following page, shows the general areas of Mayport and the Port of Jacksonville on the St. Johns River in northeast Florida. The river is the approach to Jacksonville. Significant naval and port activities are indicated.

Figure V-2 shows the St. Johns River entrance and the Mayport Naval Station. Most of the station is less than 10 ft above mean sea level (MSL). The airfield runway is 14 ft above MSL. There is no sheltering topography in the area, with little elevation north or south along the coast above 20 ft MSL.

This hurricane haven evaluation was prepared by J.D. Jarrell and A.B. Lund of Science Applications, Inc. (SAI), Monterey, CA 93940.

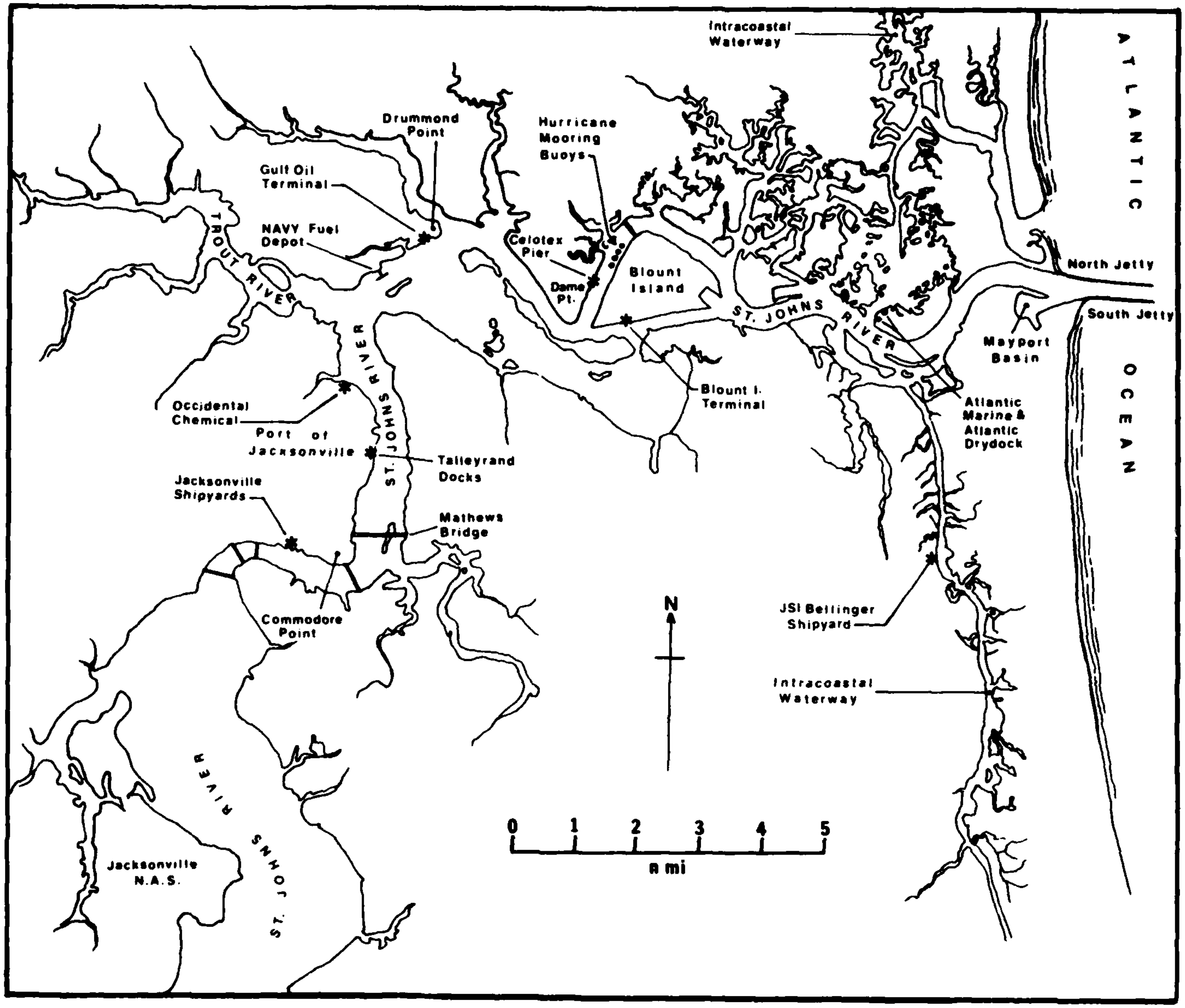

Figure V-1. St. Johns River, FL, including Mayport and the Port of Jacksonville.

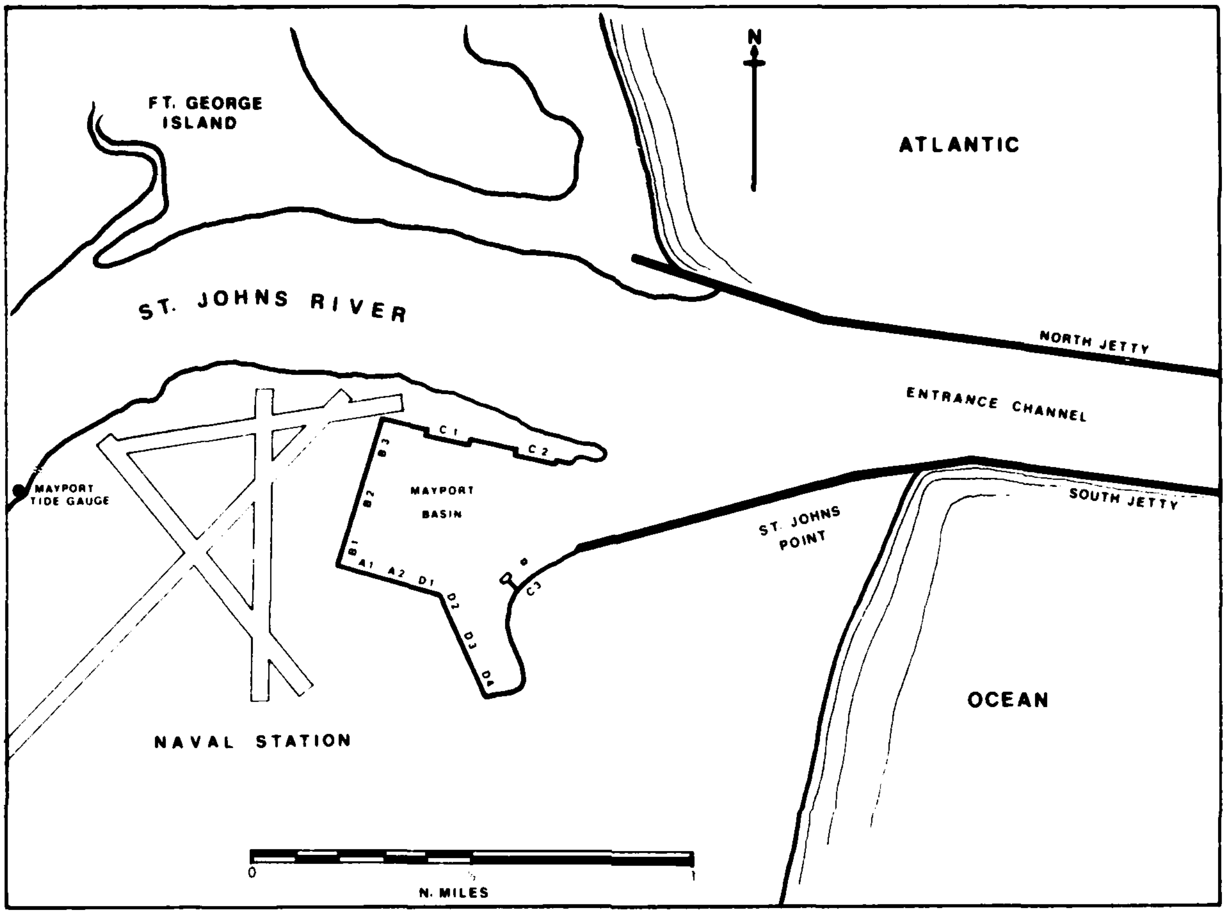

Figure V-2. St. Johns River mouth and Mayport Naval Station.

2. THE HARBORS AND THEIR FACILITIES

2.1 NAVAL STATION (MAYPORT BASIN)

The Mayport Basin is located on the south side of the St. Johns River just inside the entrance jetties and westward of St. Johns Point. Berths consist of the two primary carrier piers (C1 and C2), another carrier berth at dolphins (C3), and several other piers for smaller naval vessels. Berths B2 and B3 have also been used as a carrier pier. Depths at all piers except A1 are silted to about 38 ft at mean low water (MLW) and are expected to be dredged to 45 ft in 1982. Pier heights are 11 ft at delta piers and 12 ft above MLW at Bravo and Charlie piers while normal high tide is 5 ft above MLW.

2.2 BLOUNT ISLAND TERMINAL

The Blount Island Terminal is located about nine miles upriver from the entrance jetty, on the north side of the main channel. The facility is owned and operated by Jacksonville Port Authority (JPA). In 1981 the terminal had 3550 ft of usable berthing space, with a deck height of 9 ft above MLW and a depth alongside of 38 ft at MLW.

2.3 CELOTEX CORPORATION PIER

The Celotex Corporation pier is located at Dames Point just upriver from Blount Island. Privately owned, the terminal has 635 ft of berthing, a deck height of 10 ft above MLW and depth alongside of 32 ft at MLW.

2.4 GULF OIL TERMINAL

The Gulf Oil Pier is located at Drummond Point. It is a private terminal that has a berth of 200 ft with dolphins, a depth of 38 ft at MLW and a pier height of 12 ft above MLW.

2.5 NAVY FUEL DEPOT

The Navy Duel Depot is located about 16 miles upriver, just upstream from Drummond Creek. It has a face of about 400 ft with overall length 920 ft dolphin-to-dolphin, a deck height of 11.7 ft above MLW and a design depth of 38 ft at MLW alongside.

2.6 JACKSONVILLE BULK TERMINALS (OCCIDENTAL CHEMICAL)

The Jacksonville Bulk Terminal is located about 18 miles from the mouth of the St. Johns River. It features a 1000 ft berth, with 36 ft at MLW alongside and a deck height of 10 ft above MLW.

2.7 TALLEYRAND DOCKS AND TERMINAL

The Talleyrand Terminal is located approximately 1.8 miles below the John E. Mathews Bridge. The terminal consists of over 2800 ft of marginal wharf with a depth alongside of 38 ft at MLW and a deck height of 8 ft above MLW.

2.8 SHIP REPAIR FACILITIES

Navy ships are assigned repair availabilities under the Supervisor of Shipbuilding, Conversion, and Repair (SUPSHIPJAX) by force and type commanders. These repairs may take place at diverse locations dependent on ship size and degree of repair. Locations include:

a. Jacksonville Shipyards, Inc. (JSI) commercial yard - in the lower harbor about 22 miles upriver.

b. JSI Bellinger Shipyard Division - off the St. Johns River south along the Atlantic Intracoastal Waterway.

c. Atlantic Marine, Inc. - on the Intracoastal Waterway at the north side of the main channel of the St. Johns River.

d. Atlantic Dry Dock - on the Intracoastal Waterway north at St. George Island, next to Atlantic Marine, Inc.

e. Various leased facilities at Naval Station Mayport.

2.9 REFERENCES AND CHARTS

The reader is referred to the following publications for details of the harbor and its facilities:

DMA Hydrographic Center Publication 940, Chapter 8, Fleet Guide to Mayport

DMA Hydrographic Center Chart 11490, Approaches to the St. Johns River

DMA Hydrographic Center Chart 11491, St. Johns River

U.S. Dept. of Commerce, United States Coast Pilot 4, Atlantic Coast, Cape Henry to Key West.

3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

3.1 TUG AVAILABILITY

Local sources at Mayport indicate that the availability of tugs should be adequate in the event of orderly preparations for a possible hurricane strike. The experience of preparations for hurricane David in 1979 indicated no extraordinary problems in obtaining tug services.

3.2 HURRICANE ANCHORAGE

There are no recommended hurricane deep draft anchorages in the Mayport area. The offshore designated anchorages do not have holding adequate for hurricanes. On the northwest side of Blount Island four hurricane buoys have

been designated for the relocation of Navy Yard craft from Mayport. Further upriver near downtown Jacksonville, just downstream from the Mathews bridge, is a designated anchorage considered adequate by most. However, with the ready availability of excellent piers nearby at the port, anchoring is not considered the best choice in the event of a tropical cyclone's approach.

3.3 HURRICANE PLANS AND PREPARATION

Tropical cyclone conditions of readiness are set for the Jacksonville area by COMSEABASEDASWWINGSLANT located at the Naval Air Station (NAS) Jacksonville. In unusual circumstances the Commanding Officer of Naval Station Mayport may set higher conditions of readiness and retains final judgement for the Naval Station. NAVSTA Mayport Hurricane Berthing and Sortie actions are established in SOPA Mayport Instruction 3141.1 series. SOPA Mayport is located physically at Mayport.

4. TROPICAL CYCLONES AFFECTING MAYPORT

4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of Mayport is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected Mayport in some way, so to some extent this criterion is arbitrary. Information on tropical cyclones that passed near Mayport is available as far back as 1871. Data for this entire period was used to generate the seasonal, probability, time to closest point of approach (CPA) and direction of approach information presented in Figures V-3 through V-9.

Although tropical cyclones have occurred in the North Atlantic during all months of the year, the majority of those which threaten Mayport occur from June through October (Mayport's official hurricane season). A few have occurred in May, November and December. None have affected Mayport in January through April in the Period of 1871 through 1979. Figure V-3 depicts the monthly summary of tropical cyclone occurrences based on data for the 109 years, 1871-1979. Of the 175 tropical cyclones which threatened Mayport in this 109-year period (nearly 1.6 threats per year), 168 occurred in the months of June through October with the peak threat in September and October.

Figure V-4 displays the storms as a function of the compass octant from which they approached Mayport. The circled numbers indicate the number of cyclones which approached from that octant. The open numbers represent the same information as a percentage of the total. (Totals are slightly different from

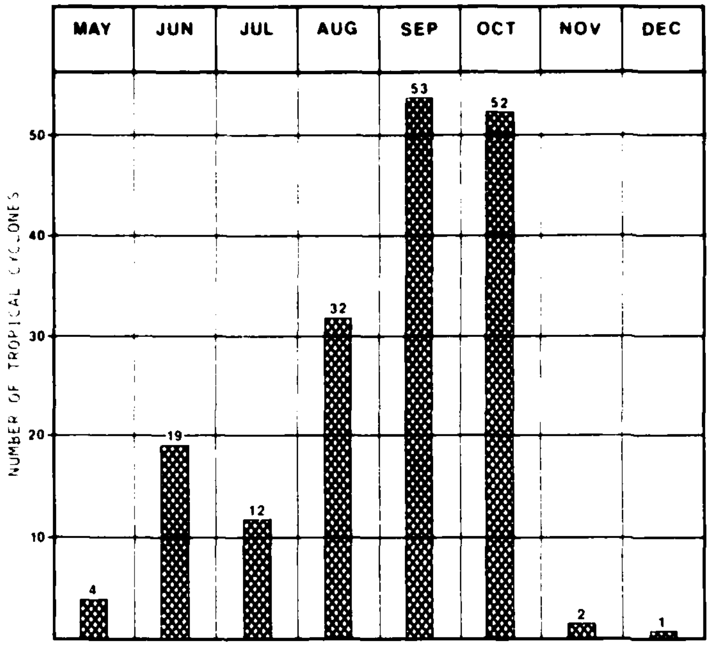

Figure V-3. Seasonal distribution of tropical cyclones passing within 180 n mi of Mayport, May-December (based on data from 1871-1979). Monthly totals are shown above each column.

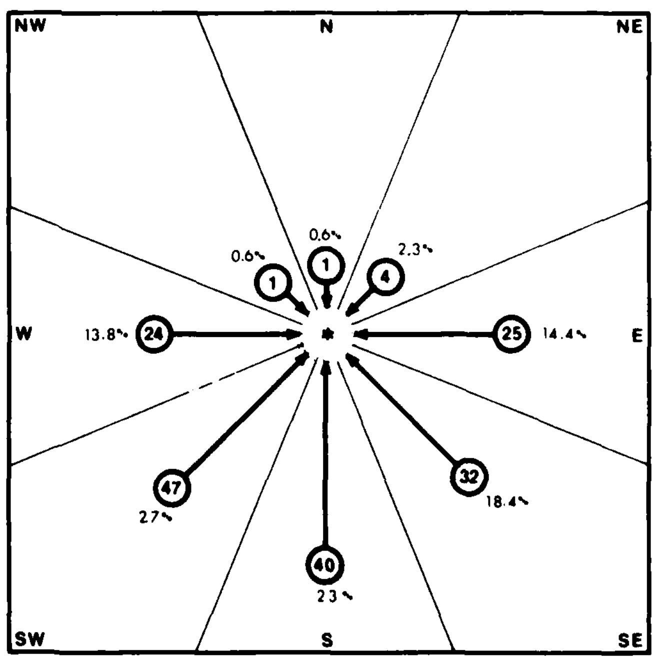

Figure V-4. Directions of approach of tropical cyclones toward Mayport during May-December (based on data from 1871-1979) and passing within 180 n mi of the port. Numerals in circles show the number of tropical cyclones approaching from each octant; the percent figure is the percentage of the total sample that approached from that octant.

Figure V-3 since looping storms may approach more than once.) There are two well defined tracks for storms threatening Mayport (also see Figure V-5), one from east of the Antilles (predominates August/September) and the other from the Caribbean (predominates late September/October).

The majority of Mayport's threats occur from storms which cross over some portion of the Florida peninsula. These storms, of course, tend to be diminished in intensity because of the land effects (friction and reduction of water surface as a heat source). Very rarely do storms make landfall in the Mayport area without already having traveled over some portion of the Florida peninsula. The low frequency of tropical cyclones striking the northeast coast of Florida directly is most likely due to the fact that the orientation of the coastline above Palm Beach is parallel to the mean storm track. Overwater storms tend to move toward Savannah, GA. Thus most hurricanes have tended to move parallel to the coastline, remaining well offshore or have crossed over land, losing much of their energy before reaching Mayport. The notable exception would be Hurricane Dora of 9 Sep 1964, which approached directly from the east-southeast. It is evident from Figure V-4 that the threat of cyclones approaching Mayport is distributed widely from the east through south to west. Dora is considered to be the worst storm to impact the Mayport area this century, with accompanying strong winds at both Mayport and Jacksonville (80+ kt gusts) and a major storm surge on the St. Johns River. Generally storms which cross the Florida peninsula south of Mayport will regain strength over water but as they strengthen they are usually moving away from Mayport. These storms would be a threat to any group of ships which had sortied from the Mayport/Jacksonville area.

Figures V-5 through V-9 are a statistical summary of threat probability based on tropical cyclone tracks for the years 1871-1979[1]. The data is presented seasonally with solid lines representing "percent threat" for the 180 n mi circle surrounding Mayport. The heavy solid lines represent approximate approach times to Mayport. For example, in Figure V-8, a tropical cyclone located near 25N, 76W in September has approximately a 40% probability of passing within 180 n mi of Mayport and if the speed remains close to the climatological normal it will reach Mayport in about 2 to 3 days.

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[1] Track information was obtained from National Climatic Center, Asheville, NC.

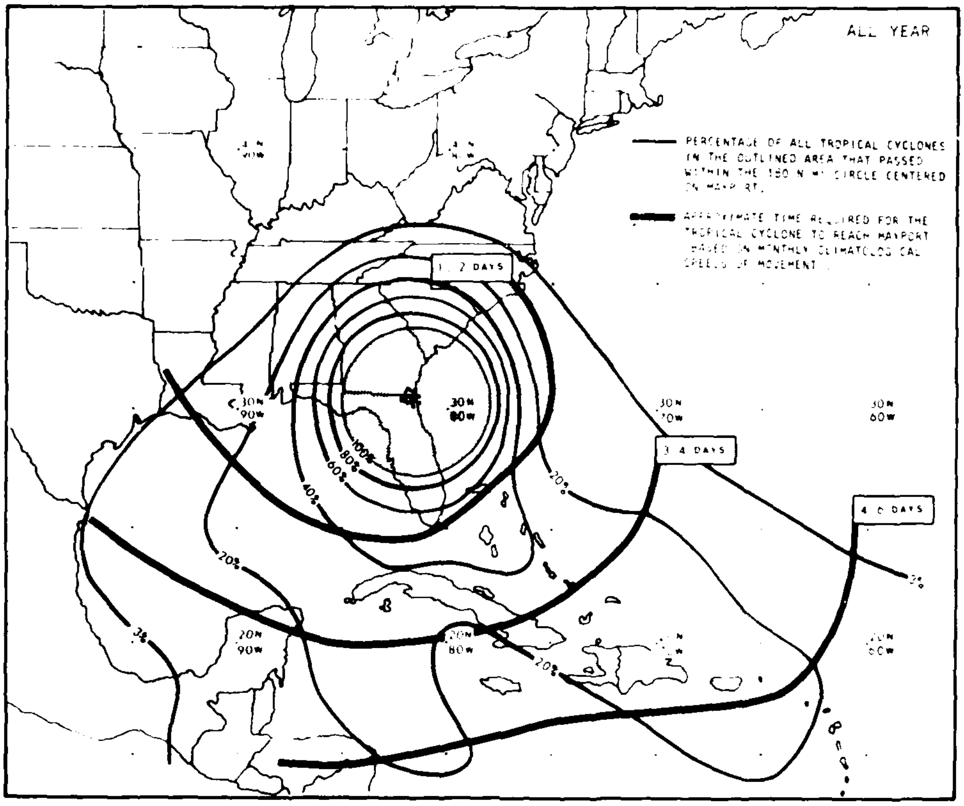


Figure V-5. Annual probability that a tropical cyclone will pass within 180 n mi of Mayport (based on data from 1871-1979).

Annually, as shown in Figure V-5, the major lines of approach to the Mayport area are along an axis near the Bahamas and an axis from the western Caribbean. A less active axis originates in the central Gulf of Mexico. Figure V-6 illustrates that the western Caribbean axis is predominant during the period January to June, with a lesser probability of systems threatening from the central Gulf. There is also a high probability (but low frequency of occurrence) axis from the direction of the Bahamas. June is the predominant threat month for this period. July and August see a major increase in activity and shift in the probability axis (see Figure V-7) to near the Bahamas causing most storms to either strike eastern Florida or pass offshore to the east. The increase in frequency during this period occurs mostly during the month of August. In September tropical activity peaks. An axis of both higher probability and frequency lies just south of the Bahamas through the lesser Antilles. These tropical cyclones generally recurve south of the Mayport area with many passing over the Florida landmass and a few passing offshore to the east. Another threat region, but less active, is the Gulf of Mexico and western Caribbean, with most systems ultimately passing over land. Then in the October-December

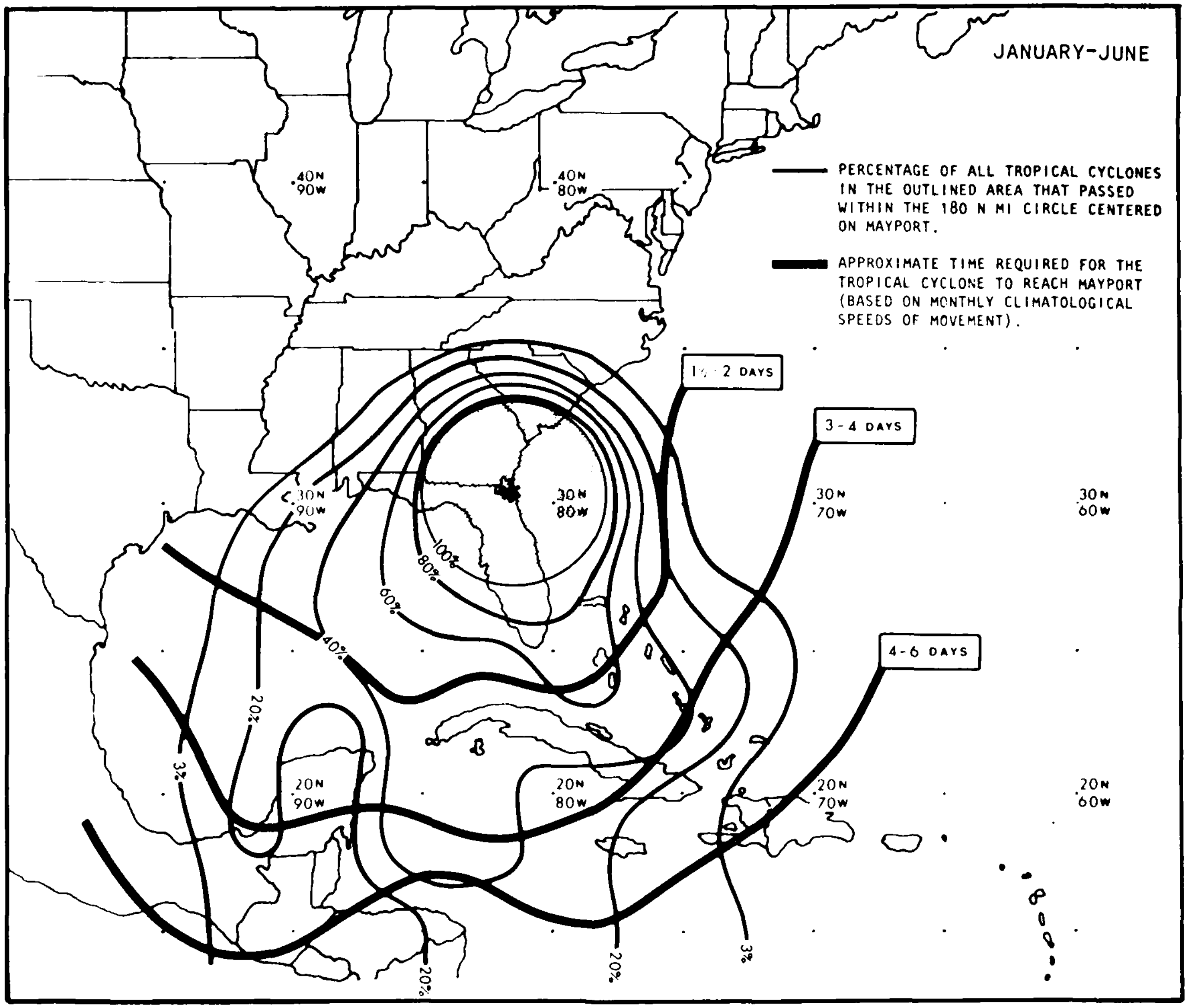


Figure V-6. Probability that a tropical cyclone will pass within 180 n mi of Mayport during the months of January-June (based on data from 1871-1979).

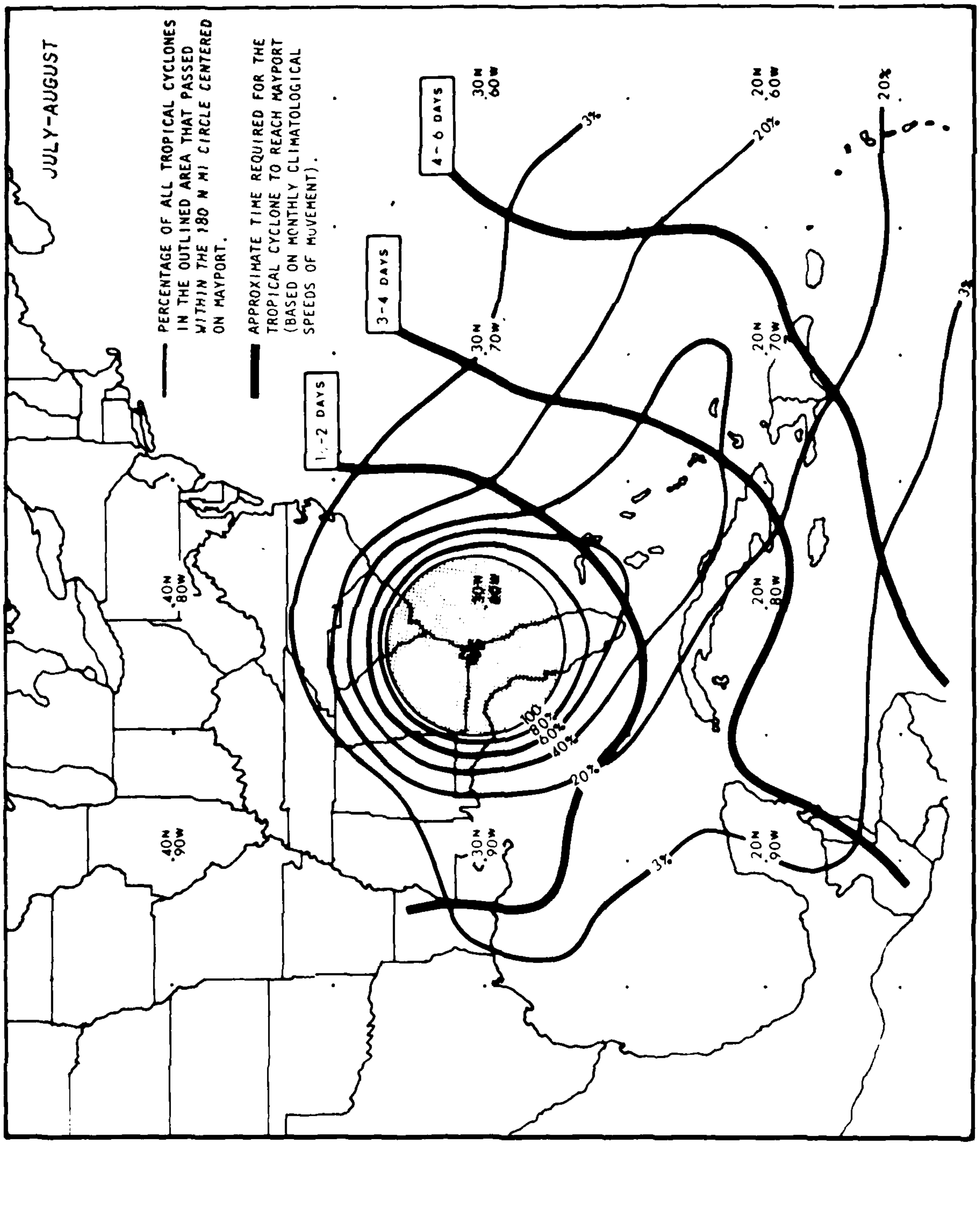


Figure V-7. Probability that a tropical cyclone will pass within 180 n mi of Mayport during July and August (based on data from 1871-1979).

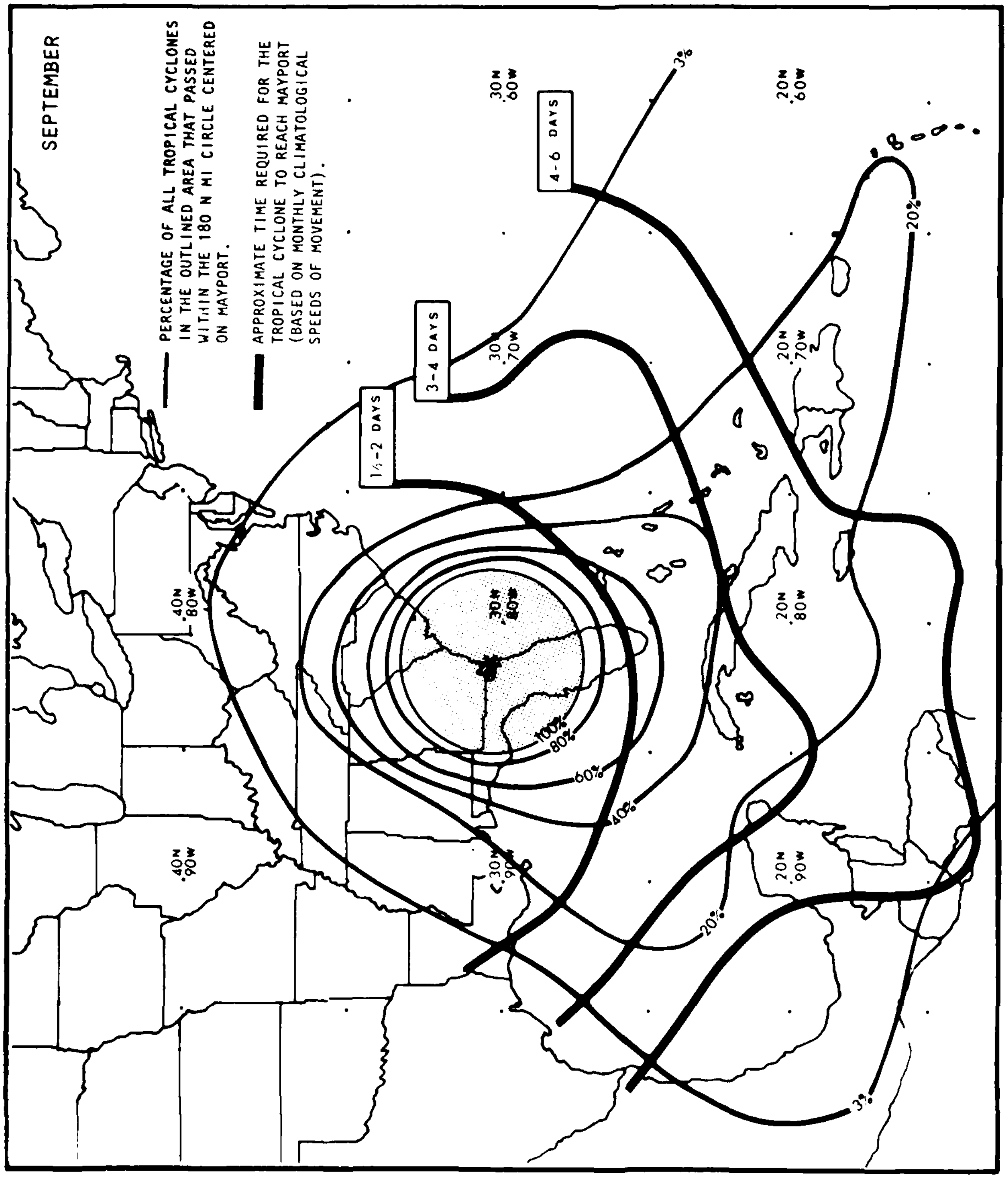


Figure V-8. Probability that a tropical cyclone will pass within 180 n mi of Mayport during September (based on data from 1871-1979).

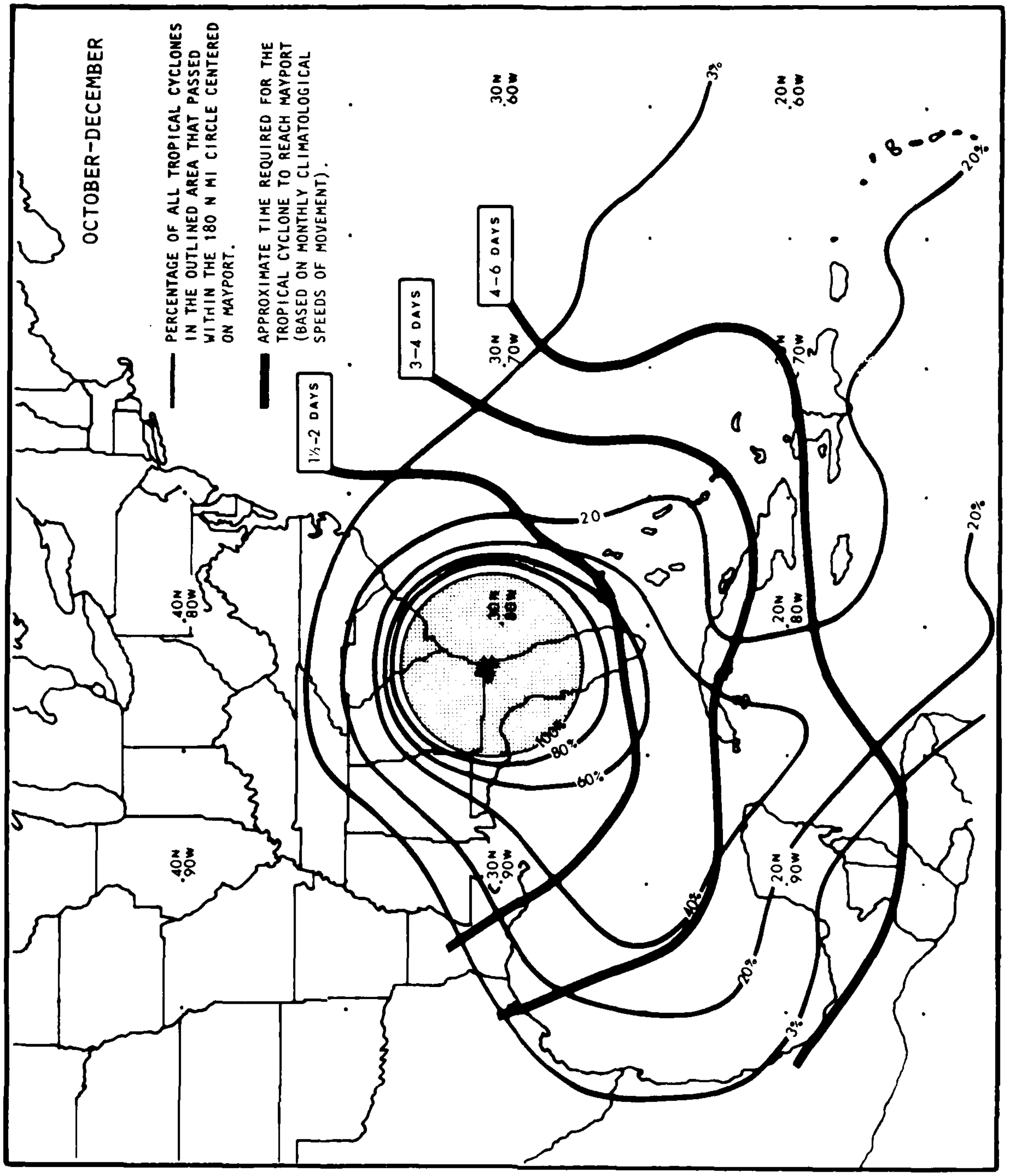


Figure V-9. Probability that a tropical cyclone will pass within 180 n mi of Mayport during the months of October-December (based on data from 1871-1979).

time frame the major activity again shifts back to the western Caribbean, with recurvature near western Cuba, and, to a lesser degree, the central Gulf of Mexico. August would appear to be the most significant threat to Mayport for the dangerous completely overwater approach, however, the significant storms have occurred during September and October. At other times of the year most tropical cyclones pass over the Florida landmass before threatening the Mayport area.

4.2 WIND AND TOPOGRAPHICAL EFFECTS

There is no topographical shelter from winds at Mayport Basin. Further up the St. Johns River, between Blount Island and downtown Jacksonville, some sheltering from south and southeast winds is offered ships because of the slightly higher elevation of land (over 20 ft above mean sea level) including some river bluffs. Wind records for the Mayport Naval Station are limited to 1956-1979. Earlier records for this study were available for 1945-1956 from Imeson Airport (no longer in existence but formerly located just north of Navy Fuel Depot) and from NAS Jacksonville. Considering the low topography throughout the local areas, the winds recorded just inland can be considered fairly representative of those occurring at Mayport.

The greatest threat on record for winds at Mayport occurred with Hurricane Dora in 1964, when maximum winds of 65 kt with peak gusts to 80 kt were recorded. The only other occurrence of such winds in over 100 years may have been the 1898 hurricane which approached the coast from the east-southeast similarly to Dora. No records of wind were available for the 1898 storm but the largest storm surge on record was generated. Thus it is the rare event of a hurricane making a completely overwater approach and making landfall near Mayport; which appears to be the most destructive. However, a more common cause of high winds at the port are the storms approaching overland as Figure V-10 shows, placing Mayport in their dangerous semicircle.

Figure V-10 depicts the track segments of the eight tropical cyclones that occurred between 1945 and 1979 which resulted in gale force winds ($\geq$34 kt) at Mayport. The dotted segment is when winds were $\geq$22 kt for these selected storms and the solid portion of the track segments is when winds were $\geq$34 kt. Mayport is, in effect, in the shadow of the Florida peninsula for the majority of recurving Atlantic hurricanes. In fact, of the 118 tropical storms and hurricanes which came within 180 n mi of Mayport only 26 passed offshore to the east without making landfall on the Florida peninsula.

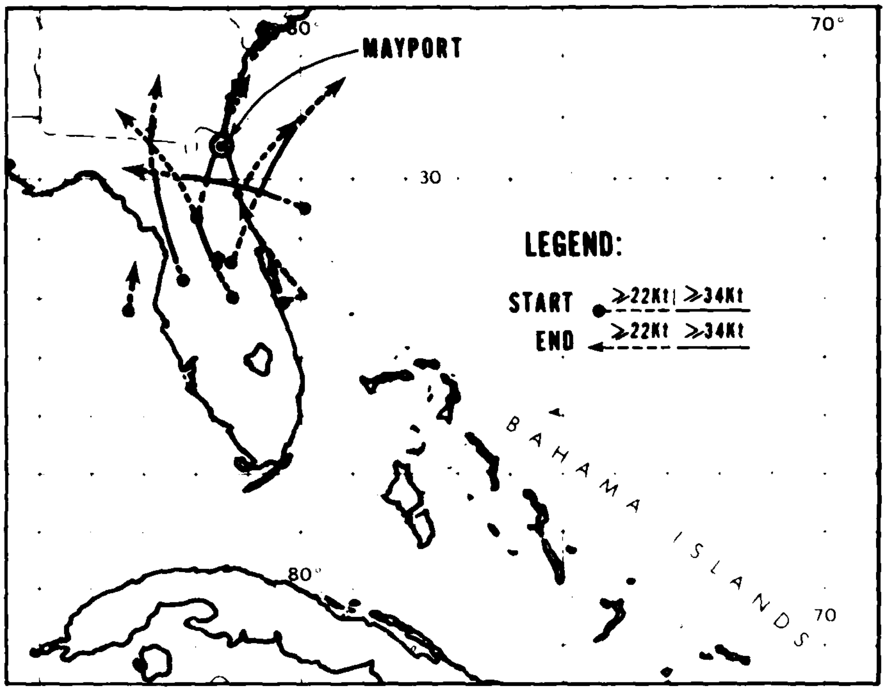
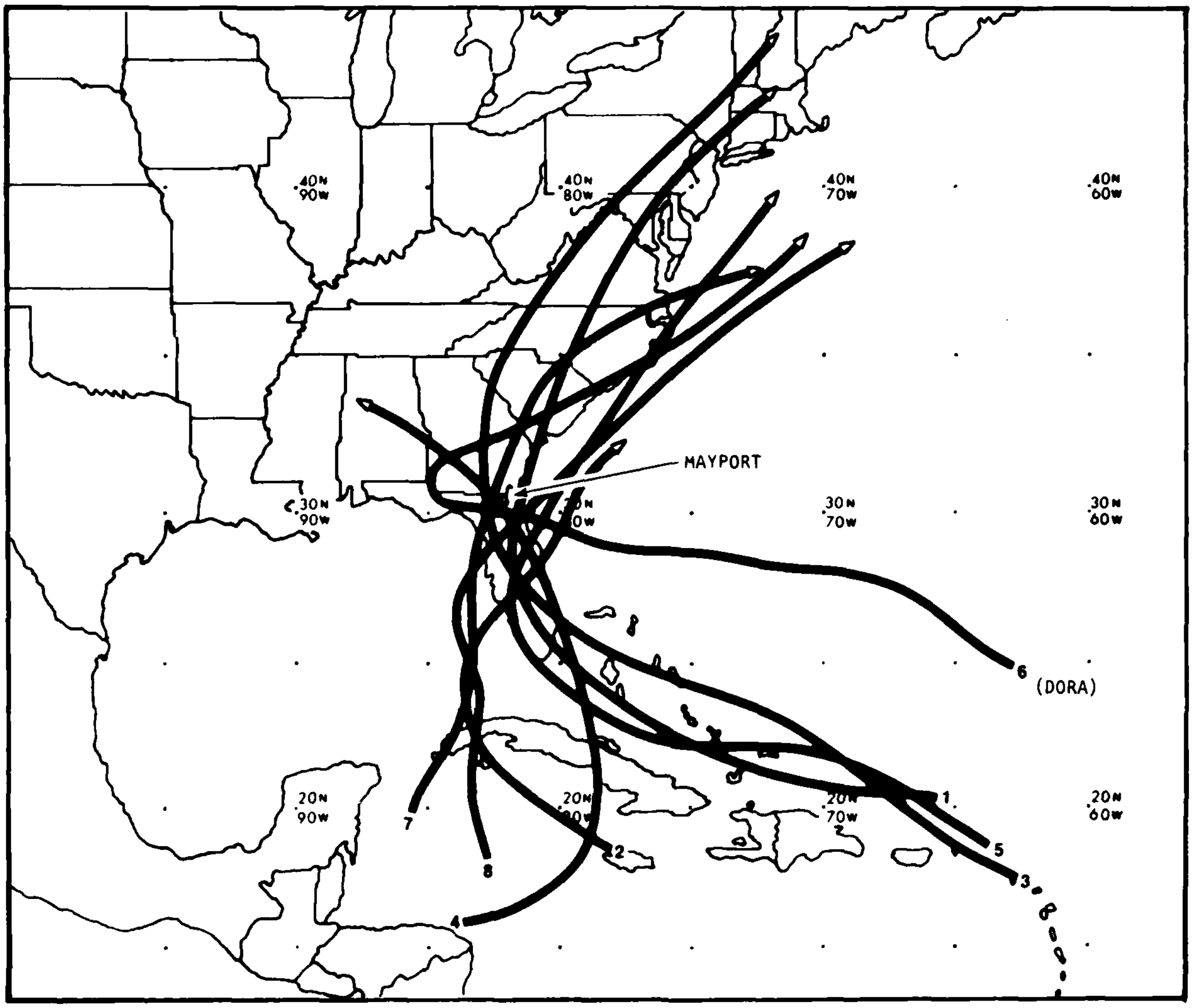


Figure V-10. Positions of eight tropical cyclones that produced winds of gale force or greater at Mayport during the period 1945-1979. Indicated are the center positions for these storms when winds $\geq$22 kt occurred at Mayport.

Figure V-11 shows expanded portions of the tracks of tropical cyclones (1945-1979) which produced gale force or greater winds at Mayport (Jacksonville). Hurricane Dora's winds exceeded 50 kt for a full 12-hour period. At Mayport Naval Station over 100 large trees were uprooted by these winds. Seven of the eight cases depicted in Figures V-10 and V-11 occurred in the August, September and October period. An examination of the direction of maximum recorded wind noted in Figure V-11 finds that the eastern components (north through south) are predominant. If any one wind direction was to be used as a basis for storm preparation it should be northeast, based on climatology. Of course this must be tempered by the intensity, size and location of the individual approaching storm.

4.3 WAVE ACTION

Mayport Basin is somewhat susceptible to wave action because of its northeast exposure through the entrance channel to the open sea. Harbor personnel indicated that swell entering from between the jetties can be a problem in the southwest corner of the basin, near B-1 and A-1. During Hurricane Dora a street adjacent to one of the Delta piers was buckled by pounding surf and the west sea



NO.	DATE OF MAXIMUM WIND	MAXIMUM SUSTAINED WIND	OBSERVATION POINT
1	16 SEP 1945	NNE 38 KT	IMESON AIRPORT
2	23 SEP 1947	ENE 36 KT	IMESON AIRPORT
3	27 AUG 1949	ESE 42 KT	NAS JAX
4	18 OCT 1950	NNE 40 KT	NAS JAX
5	11 SEP 1960	NE 37 KT	NS MAYPORT
6	9 SEP 1964	N 65 KT	NS MAYPORT
7	6 JUN 1968	NNE 38 KT	NS MAYPORT
8	19 OCT 1968	ESE 34 KT	NS MAYPORT

Figure V-11. Tracks of tropical cyclones that produced winds of gale force or greater ($\geq$34 kt) at Mayport 1956-79 and at Jacksonville 1945-56.

wall suffered considerable damage[2]. The effects of wave action are magnified as storm surge increases the water level in the channel entrance, between the jetties. The jetties are frequently inundated with a sheet of water caused by gale force or greater winds from extratropical storms (Northeasters[3]). This results in an extreme frothing action in the channel, masking channel markers, thus making entrance or exit very dangerous, especially after dark. Similar effects would be caused by gale force or greater winds from tropical cyclones.

4.4 STORM SURGE AND TIDES

Although destructive winds have been an infrequent occurrence at Mayport, storm surge has occurred much more frequently. Storm surge is the major threat to shipping and personnel in the area. The surge height varies significantly over short distances with maximum heights occurring along the beach front and the entrance jetties at Mayport, then decreasing rapidly up the St. Johns River. This rapid dissipation of surge energy is due mainly to the absorptive effects of the marsh areas along the Atlantic Intracoastal Waterway. For example, a 10-ft surge at Mayport Basin entrance would be down to 8 ft at the town of Mayport 2 miles further upstream. Table V-1 provides a measure of the degree of flooding that could be expected from a high storm surge striking the low elevation countryside. For example the 3 to 10 ft elevation of Fort George Island would be completely inundated by an 11-ft tide. The tide figures do not include the amounts attributable to beach runup which can produce even higher water levels. Table V-2 provides actual water levels (derived from either tide gauge recordings or high water marks) from past hurricanes which struck the Jacksonville/Mayport area. These values are above mean sea level, thus indicating actual heights of water, a presentation which tends to mask the amount of potential storm surge unique to each storm. For example, an actual storm surge of 8 ft can create water level extremes at Mayport of 6.1 ft above MSL if occurring at the time of mean low water (-1.9) or something less than 10.6 ft above MSL if occurring at the time of mean high water (+2.6). Generally a hurricane, such as Dora (1964) approaching nearly perpendicular to the coast, is expected to produce major storm surges.

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[2] The Mayport Mirror, Vol. VII, No. 8, Mayport, FL, 16 Sep 1964.

[3] Northeaster (northeast storm) - a storm occurring in early fall or early spring, within 100 n mi of the coast, bringing frequent gale force winds. Attributable to a cold front passing through, then stalling, followed by a strengthening high pressure area. Northeast winds set up for about 48 hours.

Table V-1. Flood potential near Mayport. Elevations of various locations in Mayport area, related to Army Corps of Engineers design high tide levels (not including runup)[4]. All levels referenced to National Geodetic Vertical Datum of 1929, which approximates to mean sea level.

Location	Range in Elevation	Design Hurricane Tide[6]
Mayport	3-10 ft	8-9 ft
Ft. George	3-10 ft	10-11 ft
Jacksonville	3-15+ ft	4-6 ft
Seminole Beach	8-15 ft	10-11 ft
Atlantic Beach	8-12 ft	10 ft
Neptune and Jacksonville Beach	7-12 ft	10 ft

Table V-2. Hurricane water levels at selected locations in feet above National Geodetic Vertical Datum of 1929[5].

Date (Hurricane Name)	Mayport St. John's River	Jacksonville St. John's River	Atlantic Blvd. at Miller's Creek	McCoy's Creek at Stockton Street	Trout River at S.A.L. Railroad Bridge	Atlantic Beach	Jacksonville Beach
Oct. 2, 1898	8-10						
Oct. 11-18, 1910	4.5						
Sept. 6-20 1920	4.3			8.8	4.0		
Oct. 19, 1944	5.5	4.8		7.3	4.4	10.8	12.3
Oct. 7-9 1946	4.3	3.0					
Oct. 15-19, 1950	4.8	4.7	4.5	7.1	4.6		
Sept. 9-10 1964 (Dora)	5.5	5.7	6.8	7.4	4.8	6.0	5.5
Oct. 19, 1968 (Gladys)							1.3

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[4] U.S. Army Corps of Engineers

[5] U.S. Dept. of Commerce, NOAA, Storm Evacuation May T-15072, Jacksonville, FL.

[6] Design Hurricane Tide - for this particular study, the tide generated by a hurricane which approximates a 100-year storm.

It should be remembered, however, that the hurricane of 19 October 1944 approached from over land and generated a significant storm surge. This large surge was apparently the result of the combined effects of a Northeaster and the hurricanes easterly winds. The hurricane of 2 Oct 1898 apparently produced the highest storm surge on record at Mayport. This storm made landfall north of Fernandina Beach after approaching on an over-water track similar to Hurricane Dora's.

The National Weather Service issues storm surge predictions every 6 hours for the coast using selected points 8 miles apart. These predictions are based on the SPLASH model and are available for 3 classes of hurricanes (Category 1, 2/3 and 4/5) and for any landfall point. For instance a severe, worst case hurricane category 4 or 5 SPLASH prediction is 16.2 ft of storm surge. This value, of course, must be added to the values of the astronomical tide expected at the times of maximum surge. Hurricane Dora would be classed as a category 2 storm.

The upper St. Johns River, which widens considerably, apparently has an impact on the effects of storm surge in the area. On 9 Sep 1964 Dora produced what would be considered a normal profile with highest tides at the channel entrance decreasing toward downtown Jacksonville. The next day, 10 Sep, Dora was still located nearby to the northwest giving quite strong southeasterly winds over the area. These winds in effect produced not only a minor surge at the river mouth, but also apparently produced a surge near downtown Jacksonville caused by the winds blowing from south to north over the wide body of water on the upper St. Johns River. Thus on 10 Sep the highest surge for Jacksonville of 5.5 to 5.7 ft above MSL was observed.

Astronomical tides have important considerations other than the relationships to storm surge, when deep draft vessels are navigating the lower St. Johns River. Naval vessels moving in and out of Mayport basin through the entrance channel should not have problems except at times of very low tides. This could affect the timing by a few hours of when to sortie a carrier from the basin. Further upriver the state of flood/ebb will be of major concern to other deep draft vessels, especially tankers (some over 33 ft draft) proceeding to and from the Navy Fuel Depot. At Mayport the tide rises about 1 hour before the current starts flooding. Care must be used if dependent on the high water slack, since near downtown Jacksonville, the tide drops about 1 hour before the current starts running out, then drops very fast. Due to tidal currents in the river at the port of Jacksonville, it is recommended that ships take precautionary measures and maneuver at or near times of slack water[7].

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[7]Fleet Guide, Mayport, FL.

Generally, according to the St. Johns Bar Pilots, some rules for moving ships in the river are:

(1) Over 33 ft draft, move out or in on flood current.

(2) Over 33 ft draft, take out at start of flood.

(3) Bring in 32 ft draft or greater on start of flood.

(4) On ebb don't move over 32 ft draft ships.

Such rules are stated more completely elsewhere, but what should be remembered is that such conditions must be taken into account when planning a sortie of deep draft vessels or a move of vessels from Mayport to Jacksonville.

Wind can have a pronounced local effect on tidal currents. With a strong easterly wind and a flood current, expect higher water levels, and with a strong westerly wind and an ebb, expect extremely low water. Wind also has a significant effect on currents at the entrance between the jetties. The Bar Pilots report that 1 hour after the beginning of a blow from any direction from north th ;h east to south, a very strong current sets with the wind across the end of the jetties, and the condition is usually dangerous; when such winds reach gale force, the positions of the buoys should not be relied upon as they may drag from station.[8] Heavy rains upriver can also be a factor, amplifying the effect of flood currents and damping the amplitude of ebbs.

Typical spring high tides for Mayport are about 2.9 ft above MSL. The mean tidal range is approximately 4.9 ft at the channel entrance, 4.5 ft at Mayport, 3 ft at Dame Point and 1.2 ft at the Port of Jacksonville. The approximate tidal currents between the jetties is 1.9 kt on the flood and 2.3 kt on the ebb; at Mayport, 2.2 kt on the flood and 3.1 kt on the ebb. Tide tables should be consulted for the exact values for astronomical tides.

5. THE DECISION TO EVADE OR REMAIN IN PORT

Specific instructions to Navy ships for dealing with tropical cyclones are delineated in SOPA MAYPORT INSTRUCTION 3141.1 series (NAVSTA Mayport Hurricane Berthing and Sortie Bill). This primary planning document establishes provisions for the orderly sailing and berthing of Mayport units in the event that a hurricane or tropical storm threatens this area. Other sources of information on hazardous tropical cyclone weather and readiness actions are:

Fleet Guide, Pub. 940, Chapter 8
OPNAVINST 3140.24 series
CINCLANTFLTINST 5400.2 series
NWP4

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[8] Coast Pilot 4.

The evasion rationale should be based on consideration of four general factors:

1. Vessel characteristics
2. Harbor conditions
3. Most recent hurricane warning forecast
4. Storm climatology

Individual vessel factors are best determined by those responsible for each vessel. Interpretation of harbor and climatology factors are addressed in the following section.

5.1 EVASION RATIONALE

(a) The general rationale applicable to the Mayport Basin as dictated by harbor conditions is for all seaworthy units to leave. This rationale is based on the lack of terrain features that could provide shelter, the high probability of significant storm surge, and the general lack of anchorages suitable for use during a hurricane.

(b) Timing of the decision to sortie is hampered by fewer factors at Mayport than at most other Atlantic coast ports because ships can get underway and be in unrestricted waters in an extremely short time. When to move is, of course, dependent on the direction from which the tropical cyclone is approaching. The concave coastline orientation north and south of Mayport limits evasion directions to northeast through south-southeast. Taking an easterly course results in crossing the track (crossing the T) of storms that recurve. In addition, once across the track, the ship is on the side of the storm's dangerous semicircle. A recent sortie from Mayport to evade Hurricane David in 1979 resulted in the ships entering the dangerous semicircle because they did not clear far enough east before turning south. Some damage was suffered in that event. Evading to the south, while positioning the ship on the side of the less dangerous semicircle, may result in very limited maneuvering space because of the eastward curvature of the Florida coastline. Furthermore, for those storms which do not recurve, but continue on a westerly course or turn further southwest, evasion to the south can create a dangerous situation because of the closing storm track and limited available evasion routes once boxed in. Figure V-12 displays the track of two hurricanes (1929 and 1965) which could possibly have prompted an evasion to the south with the storm 36 to 48 hours out from Mayport. However, the storms then turned south through the Bahamas, passing just south of Miami. An evasion group underway in this situation would have been hard pressed to determine which way to turn since the storms could have recurved north at any time.

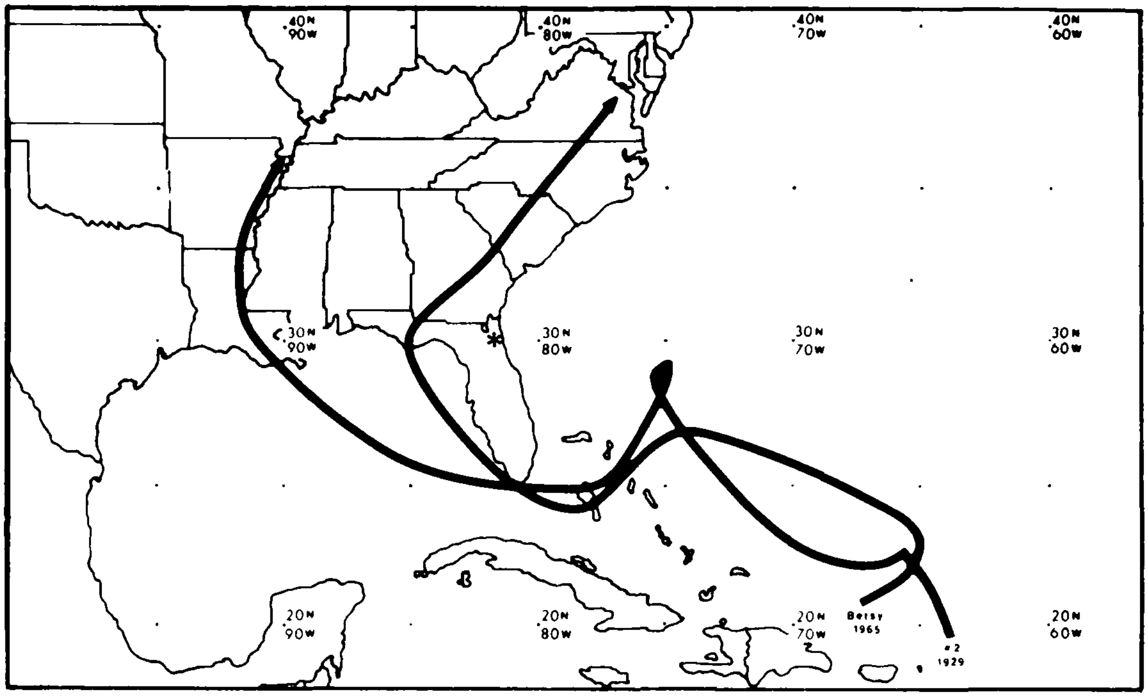

Figure V-12. Examples of two hurricanes that altered directions markedly, demonstrating that an evasion to the south must be undertaken with caution.

If sortie has not commenced within 24 hours of the expected onset of destructive winds, then a firm commitment to remain in port is strongly recommended for ships other than carriers. Smaller ships can leave the basin and go to available piers upriver, but channel restrictions and a lack of suitable anchorages dictate that the carriers must either get underway or remain in Mayport Basin. Considering the northerly off-pier beam exposure of the carrier piers, the sail area of a carrier and available higher speed, these units should generally sortie. These decisions must be tempered by the size, location and intensity of the tropical cyclone. A large intense hurricane approaching over Atlantic waters would generate swell conditions out ahead of the storm that should be considered in a late sortie decision. It may be unacceptable for the sortied ship to pass through large swell on the beam. At the opposite extreme a tropical storm that is forecast to approach over land would be of less concern considering the history of destructive wind occurrences at Mayport. In the unlikely event sortie from a storm of large areal extent is being considered into gale force winds, then a decision to stay may be necessitated by dangerous navigation conditions at the channel entrance between the jetties. In a very large storm gale force winds can extend out from the center for several hundred miles. However, only extreme circumstances should leave the planner with only 24 hours lead time to make a sortie decision. If the storm has the potential to

generate destructive winds at Mayport and if sufficient storm surge may be expected to preclude remaining tied to a pier at Mayport, then a decision to evade must be made at least 36 hours before expected strike.

(c) Storms approaching from an east through southeast direction and forecast to make landfall near Mayport have maximum climatological potential for striking with full force and for generating the highest and earliest storm surge. These storms would justify early evasive action.

(d) Storms approaching south of the Bahamas or from the Gulf or Caribbean have a high climatological potential to strike land on the Florida peninsula before reaching Mayport. For marginal hurricanes and tropical storms this landfall can reduce the intensity such that evasion is not required. However, severe hurricanes have the potential to cross land and regain or maintain much of their punch.

5.2 REMAINING IN PORT

The final decision to remain in port at Mayport or the Port of Jacksonville will depend on many parameters including the forecast wind speed at the port and the track of the tropical cyclone. In the event of a threat which merits sortieing from the port, some reberthing of disabled vessels or other yard craft will be necessary. The following considerations pertain.

5.2.1 Mayport Basin, Naval Station Mayport

In the event of a possible strike by a tropical cyclone of hurricane proportion, Mayport Basin will most likely be completely evacuated if time and upriver berthing allow. For situations of severe tropical storm force (50-63 kt), evasion by all units may not be essential. SOPA Mayport Instruction 3141.1 uses forecast winds of greater than 60 kt in the local area as the decision point of when to execute sortie actions. When winds are forecast in the range of 50-60 kt, actions may be taken to shift designated units to other hurricane berthing described in Sections 2.2 through 2.7. Mayport Basin piers are subject to total inundation with moderate storm surge. Pier heights, which are 11 to 12 ft above MLW, are subject to flooding with a surge of 6 to 7 ft. Storm tides of a height sufficient to cover the Mayport piers are periodically produced by Northeasters.

Ships are known to have remained in Mayport Basin, while others have sortied. During Hurricane Dora, 9 Sep 1964, the Destroyers NOA, TURNER, BAILEY and MERIDETH remained in the basin. The USS MERIDETH, at C-1 pier, provided wind observations through most of the storm when the station's weather office wind recorder failed. Sixteen ships evaded on 8 Sep 1964. No damage to the

ships remaining in port was noted in a news article covering the event.[2] During the passage of Hurricane David, 3-4 Sep 1979, the carrier USS SARATOGA was unable to get underway and remained in port. The SARATOGA was shifted to the Bravo piers (B-2 and B-3) for better wind orientation and tugs were used during the storm for holding the ship on and off the pier as the wind shifted. However, the maximum winds experienced were 31 kt sustained and 43 kt gusts. In the event that ships remain in the basin during a hurricane passage, the southwest corner should not be used for berthing and a general surging action should be expected throughout the basin. The Bravo piers will hold ships in a higher tide because of the set back bollards. Yard craft and disabled vessels will normally be shifted to hurricane berthing upriver before a decision to sortie has been made. Ships contemplating a sortie should plan on the early non-availability of all yard craft except for tugs. The early shifting to hurricane berths allows the full availability of tugs in the event all other ships sortie.

5.2.2 Blount Island Hurricane Anchorage

Four hurricane mooring buoys, located on the northwest side of Blount Island in the Blount Island Channel, are maintained by the Navy for use as local hurricane berths for yard craft from NAVSTA Mayport. When used, this anchorage is exposed to hurricane winds, particularly from the north and northeast. The 100-year flood level[9] of 10 ft at the channel entrance would be reduced to about 7 ft at Dames Point which is near the anchorage. A slightly lesser height could be expected at the anchorage.

5.2.3 Navy Fuel Depot

Although a good sturdy pier with ample space for hurricane berths, use of the Navy Fuel Depot is not recommended, except as a last resort. If the pier and its fueling facilities were damaged by a ship tied up during a hurricane it could have major impact on the supplying of fuel to both NAVSTA Mayport and NAS Jacksonville. The pier also has off-pier exposure to northerly winds. Generally the berth would be open if needed since tankers only berth here for about 16 hours offloading and generally would not enter a port under threat of hurricane. With a mean high water (MHW) of about 2.3 ft above MLW and a 100-year storm tide of about 7 ft, a pier height of 11.7 ft would be well above a storm surge.

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[2] The Mayport Mirror, Vol. VII, No. 8, Mayport, FL, 16 Sep 1964.

[9] 100-year flood level (flood tide) - a tide generated by a hurricane which is equaled or exceeded once in 100 years (1% chance of happening in any one year).

5.2.4 Other Local Hurricane Berthing

SOPA will assign berths for disabled vessels and other designated units in one of the following berthing locations:[10]

Blount Island Terminal
Celotex Corporation Pier
Gulf Oil Terminal
Jacksonville Bulk Terminal (Occidental)
Talleyrand Docks and Terminal

The Blount Island Terminal is poorly exposed for northerly off-pier winds and a 7-ft surge combined with a 3-ft MHW could flood the pier which is 9 ft above MLW. The Talleyrand Terminal with a deck height of 8 ft above MLW and a MHW of 2+ ft would be susceptible to flooding by a 6-ft surge as with Hurricane Dora (1964). However, the flooding of these piers does not preclude their use if the bollards are set back enough for the particular assigned craft. Large tankers can flood down in the river, but should only use areas that have been surveyed for bottom hazards.

5.2.5 Ship Repair Facilities

Ships in refit at local ship repair facilities maintain steaming readiness conditions appropriate to the type of availability assigned (TAV, RAV, SRA, ROH). Generally the commanding officer or the type commander tailors the work package to suit the desired readiness posture. A hurricane contingency can be written into a contract which requires the contractor to disable only a specified quantity of machinery at one time thus enabling the ship to maintain a readiness to get underway within a specified period of time at a specified percentage of plant capability (usually 72 hours on half boiler power). This contingency clause is expensive in terms of dollars and delays and is invoked infrequently. In most situations the government allows work to proceed unencumbered until a hurricane threat is perceived. At that point the contractor may be issued a contract change order to reassemble equipments, blank off openings, etc., on an emergency basis to prepare the ship to get underway. If a unit cannot get underway for evasion it would be towed to alternate berthing upriver. Jacksonville Shipyards (JSI) located downtown at Commodore Point is

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[10] An alternate location which may be used by SOPA Mayport, if all other space was gone, is the Seaboard Coast Line pier. It is a city owned pier downtown between the Main Street bridge and the Acosta Railroad bridge. Small vessels such as an ATF could be put there. This area of the river is subject to a moderate surge from severe southerly winds.

the only repair facility with good piers and protection from the wind. Bridge height limitations preclude access to JSI by some vessels. Bellinger Shipyard is susceptible to a 5-ft, 100-year storm tide.

5.2.6 Anchorages

The only hurricane anchorage available other than the Blount Island anchorage would be downtown near the Port of Jacksonville. Designated anchorage "D" is the overflow anchorage from the downtown berthing. Anchorage "C" is considered a hurricane anchorage, but allows less room to swing. If required, tankers could ballast down in the river opposite the port. Experience has shown that most commercial ships get underway in the event of a threat by a tropical cyclone. During the passage of Hurricane David most merchants did not come into port and those in port put to sea.

5.2.7 Advice for Small Craft and Atlantic Intracoastal Waterway (AICW) Traffic

Small craft are not located in the Mayport Basin and there is no local yacht club. Generally small craft in the lower river move up the AICW as do the Bar Pilot boats and then tie up abreast in sheltered locations. The AICW extending north from the St. Johns River is susceptible to flooding 8 to 9 ft above MSL for several miles. The AICW extending south from the St. Johns River has the potential for a 100-year storm tide of 8.5 ft MSL at the confluence, dropping off rapidly to a height of 4 ft MSL near Beach Boulevard. The areas near Ft. George Island can flood to 8 to 9 ft above MSL.

5.3 EVASION AT SEA

Evasion at sea is the recommended course of action for all seaworthy vessels when winds of greater than 60 kt are expected in the Mayport area. When storm winds of less than 60 kt are expected or if sudden storm intensification makes sortie dangerous, then local and upriver berthing may be used for all ships present. When evasion is contemplated, the importance of correctly assessing the threat posed by the storm and acting quickly so as to retain flexibility cannot be overemphasized. Each threat must be judged on its merits but the following describes the most likely threat situation and recommended course of action.

(a) <u>North Atlantic Hurricanes North of the Bahamas</u> -- tropical cyclones approaching from this sector are the greatest threat for both wind intensity and probability of high surges. The worst storm experienced this century at Mayport (Hurricane Dora - 1964) advanced on this path. These storms are the most

difficult to evade since transiting east or northeastward can position the ship in the region into which the storm may move. The likely action of the storm storm is to recurve to a more northerly path, passing well offshore from Mayport. During July and August, storms in this region have a higher probability of passing within 180 n mi of Mayport. If a storm is north of the 110^{0} true radial of Mayport, then the recommended evasion direction is south. For storms south of this radial, the strike probability is higher and therefore the recommended evasion is east from Mayport. Early departure is imperative in order to either cross ahead of the storm and obtain sea room in which to maneuver, or to run to the south clear of any possible turn back to the west or southwest.

(b) North Atlantic Hurricanes South of the Bahamas, and Eastern Caribbean Hurricanes -- tropical cyclones approaching from this region have a high probability of passing within 180 n mi of Mayport, particularly in September. During other months this situation is less common than (a) or (c). The recommended evasion direction is east then southeast.

(c) Gulf of Mexico and West Caribbean Hurricanes -- tropical cyclones approaching from this quadrant have a fairly high probability of passing within 180 n mi of Mayport (except much lower during July/August). These storms may be severe, but generally pass over land with a high percentage becoming tropical storms before passing Mayport. It is recommended that more time be allowed in watching these storms prior to sortie. If evasion is planned, a southeast departure is advisable. Some of these storms have crossed over to the Atlantic side through the Straits of Florida so caution may require a diversion further east.

5.4 RETURNING TO HARBOR

After the passage and successful evasion of a tropical cyclone, returning to harbor is itself not without hazard. There may well be sunken wrecks in the channels, there may be damage to the piers and normal alongside services may well be disrupted. There is also a high probability that channel markers and other navigation aids have shifted position or have become otherwise unreliable. The utmost caution must therefore be taken.

REFERENCES

Defense Mapping Agency Hydrographic Center, 1977: Fleet Guide Mayport, Florida, Pub. 940, Chapter 8.

Howard Publications, Inc., Jacksonville, FL: Jacksonville Port Handbook, 1981.

Neumann, C. J., G. Cry, E. Caso, and B. Jarvinen, 1978: Tropical Cyclones of the North Atlantic Ocean, 1871-1977; National Climatic Center, Asheville, NC, in cooperation with the National Hurricane Center, Coral Gables, FL.

SOPA Mayport Instruction 3141.1A.

U.S. Army Corps of Engineers, 1961: Analysis of Hurricane Problems in Coastal Areas of Florida (Survey Report).

U.S. Dept. of Commerce, 1979: U.S. Coast Pilot 4, Atlantic Coast: Cape Henry to Key West.

VI: CONTENTS

VI. KINGS BAY, GEORGIA

SUMMARY

Kings Bay, Georgia lies in marshy, flat terrain behind a long, low barrier island which separates it from the open ocean. Submarines reach their base at Kings Bay via a long channel which has been cut through the shallow coastal shelf and muddy tidal sound. The only natural shelter from winds is provided by forest and the development of a hurricane anchorage is precluded by the poor holding quality of the bottom in the sounds. Furthermore, the deeply cut access channel would be subject to sudden shoaling under certain circumstances of a hurricane strike.

The Kings Bay submarine base is evidently extremely vulnerable to the effects of a hurricane strike. Despite this potential vulnerability, the risk of submarine operations being disrupted is reduced considerably by the rarity of direct landfalling hurricanes along the neighboring coast. The more commonplace threats are posed by hurricanes which pass close offshore without making landfall or after exiting along the Florida coast to the south of the St. Marys Entrance. These hurricanes have remarkably little impact at Kings Bay and would not merit the sortie of the submarine squadron. However, sortie of ocean-going Navy units would be justified for the rare direct landfalling hurricane and more commonly, for those hurricanes approaching overland which, instead of exiting to the south, threaten to pass close to the west of Kings Bay or make a direct strike.

Some observations on the influence of the hurricane threat on future developments at the submarine base, particularly in regard to safeguarding support vessels and submarines under repair, are given.

Advice to small commercial craft in the area on securing against a hurricane threat is also provided.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Figure VI-1 shows the location of the Naval Submarine Support Base on the western shore of King Bay, which branches northwestwards from the main body of Cumberland Sound. More than half the land area depicted is marshy and lies below an elevation of 10 ft above mean sea level. Fortunately, Cumberland Island, which lies to the east of Cumberland Sound, possesses a spine of forested land which poses a continuous barrier of at least 15 ft elevation between the ocean and the inland sounds. Considerable overdredging of the natural channel from Kings Bay to the open ocean via St. Marys Entrance (a distance of 11 n mi) was needed to give deep draft submarines access to the base.

This hurricane haven evaluation was prepared by LT CDR R.J.B. Turpin, RN, Royal Navy Exchange Officer at NAVENVPREDRSCHFAC.

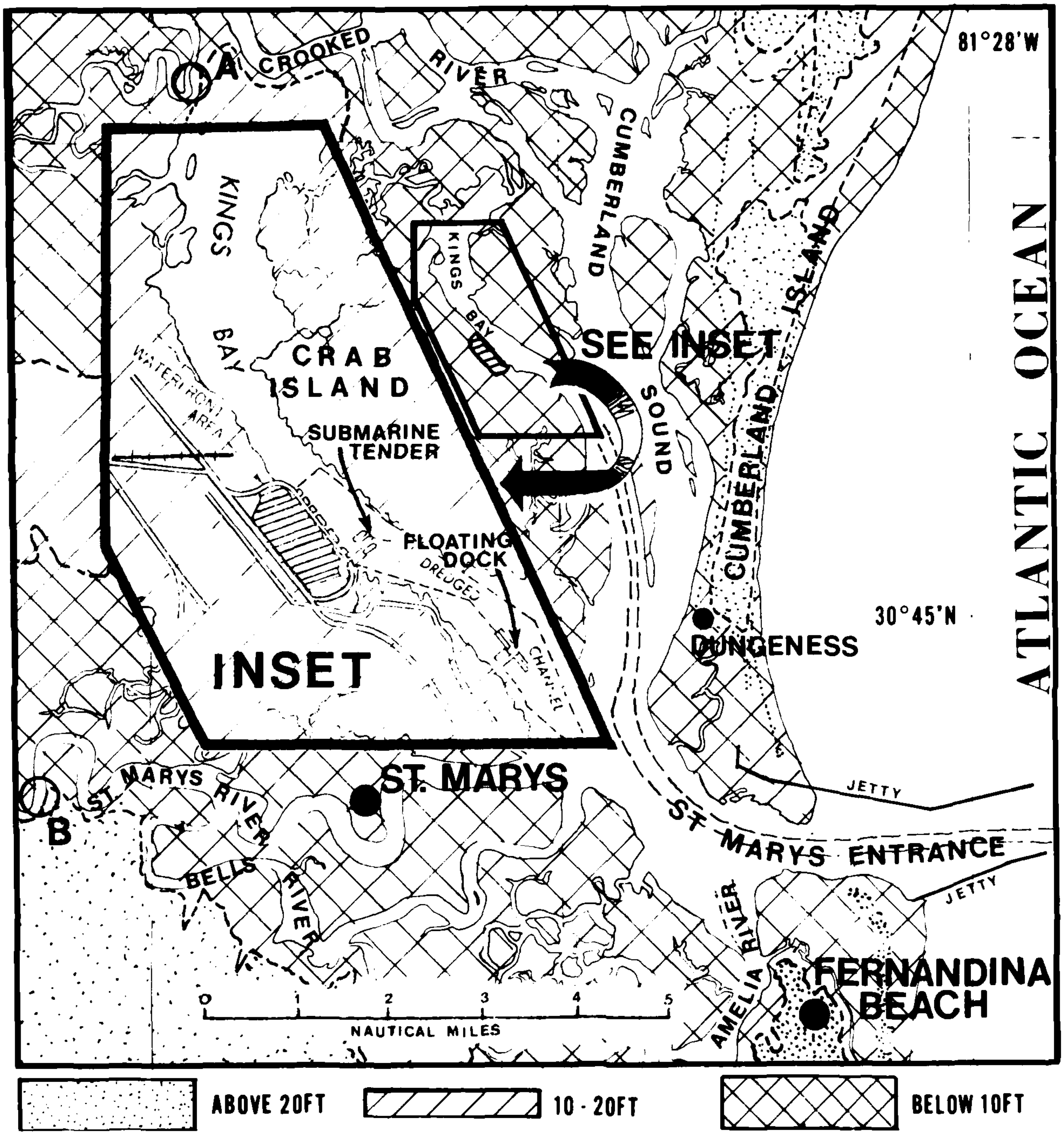

Figure VI-1. Locator map for Kings Bay. Cumberland Island and its associated sound separate the marshy coastal plain from the open ocean. The inset shows the first phase of waterfront development for the Navy Submarine Support Base. Further over-dredging of the access channel will be required by later phases of Base development. Circles A and B mark locations of two examples of hurricane holes for small craft. (Adapted from NOS/NWS Storm Evacuation Map T-15071, 1977.)

The St. Marys Entrance channel also provides access to the fishing and other commercial wharves on the Amelia River at Fernandina. Fishing vessels also berth at St. Marys on the St. Marys River, which marks the Georgia/Florida state boundary for about 60 miles inland. The St. Marys River and its tributary, the Bells River, encounter some relatively high bluffs (up to 60 ft) just west of St. Marys.

2. PORT FACILITIES

Demographic considerations were important in selecting Kings Bay as a site for a new submarine base, and consequently the base is isolated from large centers of population. Apart from the commercial maritime activities noted above at St. Marys and Fernandina and the Intracoastal Waterway traffic via the Amelia River and Cumberland Sound, the Kings Bay Naval maritime activities now predominate.

The inset in Figure VI-1 locates the floating dry dock (ARDM) mooring approximately one mile southeast of the main berthing area. Figure VI-2 provides further details of the main berthing area.

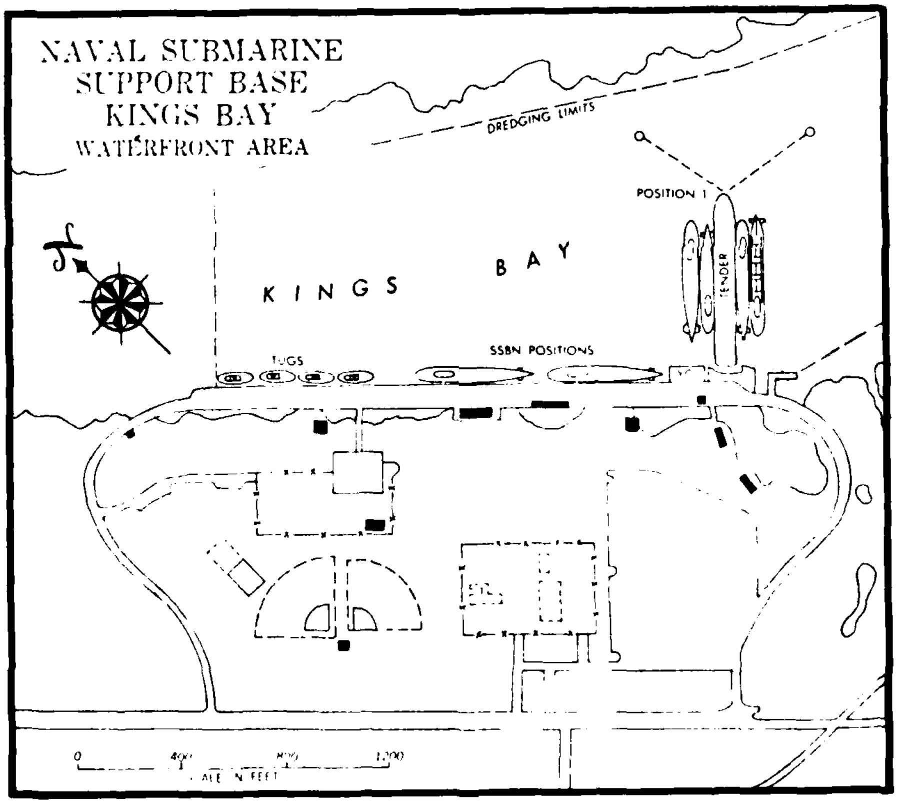

Figure VI-2. Detail of the Navy adaptation of the former Army wharf facility at Kings Bay to accomodate the first squadron of submarines. (Adapted from DMA Publication 940, Ch. 15, Fleet Guide Kings Bay, Georgia; 1979.)

Considerable further expansion of these facilities is planned which will extend the developed waterfront on the western shore of Kings Bay further northwestwards. This expansion will ultimately demand the construction of large graving docks and a further increase in the project depth of the existing dredged channels in order to accommodate deeper draft submarines.

Further details of the existing Naval facilities and the base area are provided by:

DMA Hydrographic/Topographic Center Publications, 1979, 940, Chapter 15, Fleet Guide Kings Bay, Georgia

DMA Hydrographic/Topographic Center Charts as follows:

No. 11503 Cumberland Sound - Fernandina Harbor to Kings Bay
No. 11500 St. Marys Entrance
No. 11499 Kings Bay

National Ocean Survey (Riverside, MD 20840) 1977, Storm Evacuation Map T-15071, Fernandina Beach, Florida

U.S. Coast Pilot 4, Atlantic Coast: Cape Henry to Key West.

3. HEAVY WEATHER FACILITIES

There are no designated hurricane berths or anchorages for the deep draft Navy submarines and submarine tender at the Naval Submarine Support Base. Poor holding ground in the sheltered waters of the area precludes the development of suitable anchorage for ocean-going vessels. Therefore, in the event of the Base being threatened by a tropical cyclone or other destructive weather phenomenon, sortie of all operational submarines and their tender to the open ocean is the only alternative to remaining at their normal berths. The Submarine Support Base maintains the necessary tug resources to execute sortie of these operational units. Some further provisions may be necessary for securing tugs and other support vessels against a hurricane threat, particularly if development plans require the removal of certain existing mooring buoys (see Para. 5.4).

In the event of a hurricane threat, vessels at Kings Bay will make preparations as prescribed by SOPA according to KINGSBAYINST 5400.1A.

4. TROPICAL CYCLONES AFFECTING KINGS BAY

4.1 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Kings Bay is considered a threat. Tests have shown that the climatological data for Mayport, Florida, which lies only 22 n mi south of Kings Bay, is also applicable to the Kings Bay location. Readers are referred to Para. 4.1 of Section V of this Handbook entitled "An Evaluation of Mayport, Florida as a Hurricane Haven"; the main conclusions of which are presented in Figures V-3 through V-9. The outstanding feature of tropical cyclones affecting the Kings Bay/Mayport area is that, because this portion of the Florida/Georgia coast lies parallel to the mean track of the majority of recurving threat storms, the incidence of direct landfalling tropical cyclones is extremely low. Instead, most threat storms approach this section of the coast over land or alternatively pass clear offshore without making landfall at all.

4.2 WIND AND TOPOGRAPHICAL EFFECTS

The low elevation of the marshy lands surrounding the creeks and rivers of this area (see Figure VI-1) provides little natural shelter except where drainage is adequate to support forest development. The waterfront area at Kings Bay Submarine Base is badly exposed to winds from NW through north to SE. Natural forest provides some low level shelter in the remaining sector. The relatively high (up to 60 ft) forested bluffs provide shelter to small craft on certain reaches of the St. Marys and Bells Rivers west of the town of St. Marys.

These assertions cannot be supported by measured wind data, but estimates have been made of the maximum winds experienced at the site of the Kings Bay Submarine Support Base by interpolation between recorded winds at Jacksonville, Mayport and Fernandina Beach in Florida and Brunswick in Georgia. The sole benchmark available consists of a single value for the maximum gust at the Kings Bay waterfront recorded in 1979 during the passage of Hurricane David (approximately one year after construction of the Base facilities started). The available wind records above revealed nine other tropical cyclones with wind effects in the Kings Bay area comparable with Hurricane David for the period 1944-1980. Figure VI-3 shows the complete tracks of these nine tropical cyclones for which maximum sustained winds at Kings bay were estimated to lie between 25 and 33 kt. These limits were chosen to provide a statement of significant tropical cyclone threats which would not have merited the sortie of operational vessels from the submarine base. Figures VI-4 and VI-5 depict two other families of storms for which wind effects at Kings Bay were estimated[1] to lie between 34 and 50 kt (Figure VI-4) and above 50 kt (Figure VI-5). These two figures serve to illustrate tropical cyclone threats which produced conditions at Kings Bay which could be described as "marginal" and "unsafe" respectively for operational units at the base.

A comparison of Figures VI-3, -4 and -5 provides an opportunity to characterize "safe", "marginal" and "unsafe" tropical cyclone incidents at Kings Bay. Differences in intensity and closeness of approach contribute to the distinction between the "safe" and "marginal" storms of Figures VI-3 and VI-4, but more particularly, this comparison shows the greater impact of tropical cyclones making a close pass to the west of Kings Bay. Thus it appears that in the relatively marshy flat terrain of this area, that the "dangerous semicircle" winds, when blowing across the land, are more destructive than "safe semicircle" winds blowing from the ocean. A clearer distinction separates the "unsafe" storms of Figure VI-5 from all the storms of Figures VI-3 and VI-4. The "unsafe" storms all made a direct landfall near Kings Bay after approaching from the ESE over the Atlantic branch of the warm ocean current lying to the north of the Bahamas. Hurricane Dora of 1964 is the best documented event. An eyewitness at the former Army facility at Kings Bay recalls sustained hurricane force winds with gusts to 80 kt.

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[1] Wind estimates from 18991944 are based upon storm intensity data interpreted in relation to the storm's closest point of approach to Kings Bay and its forward speed. Prior to 1899, narrative accounts of destructive effects must be relied upon. The settlement at St. Marys provided strong evidence of highly destructive winds and tides on the occasion of the 1837 storm, however, some doubt over its open ocean track exists (Ludlum, 1963).

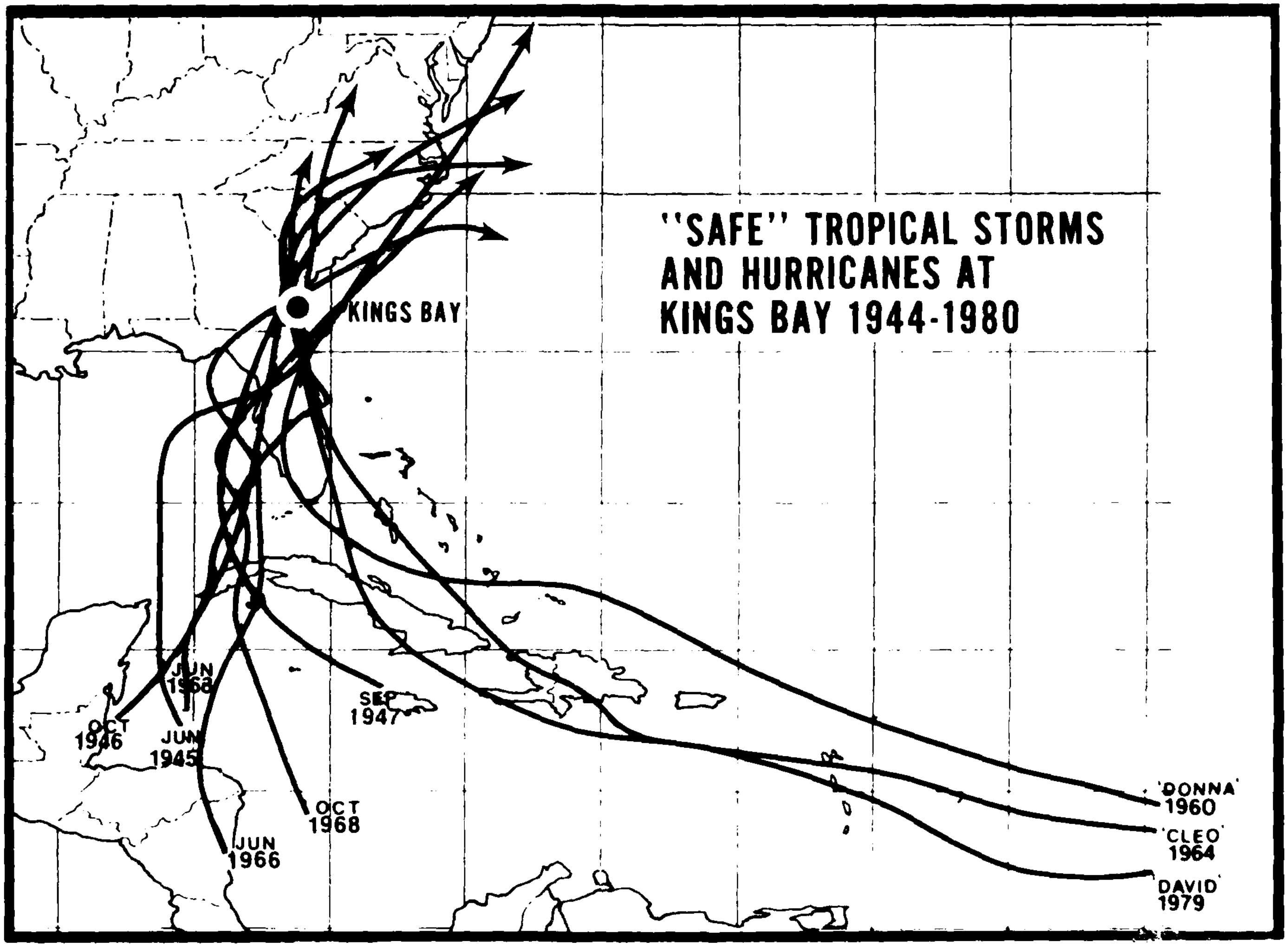

Figure VI-3. The nine tropical cyclones in the period 1944-1980 that produced strong sustained winds (25-33 kt) at Kings Bay. Two of these did not reach hurricane intensity (64 kt or greater) before landfall: Sep 1947 and Jun 1966. All nine of these tropical cyclones produced winds and tidal effects at Kings Bay that are judged "safe" for submarines and their tender at the base. (See also Table VI-2.)

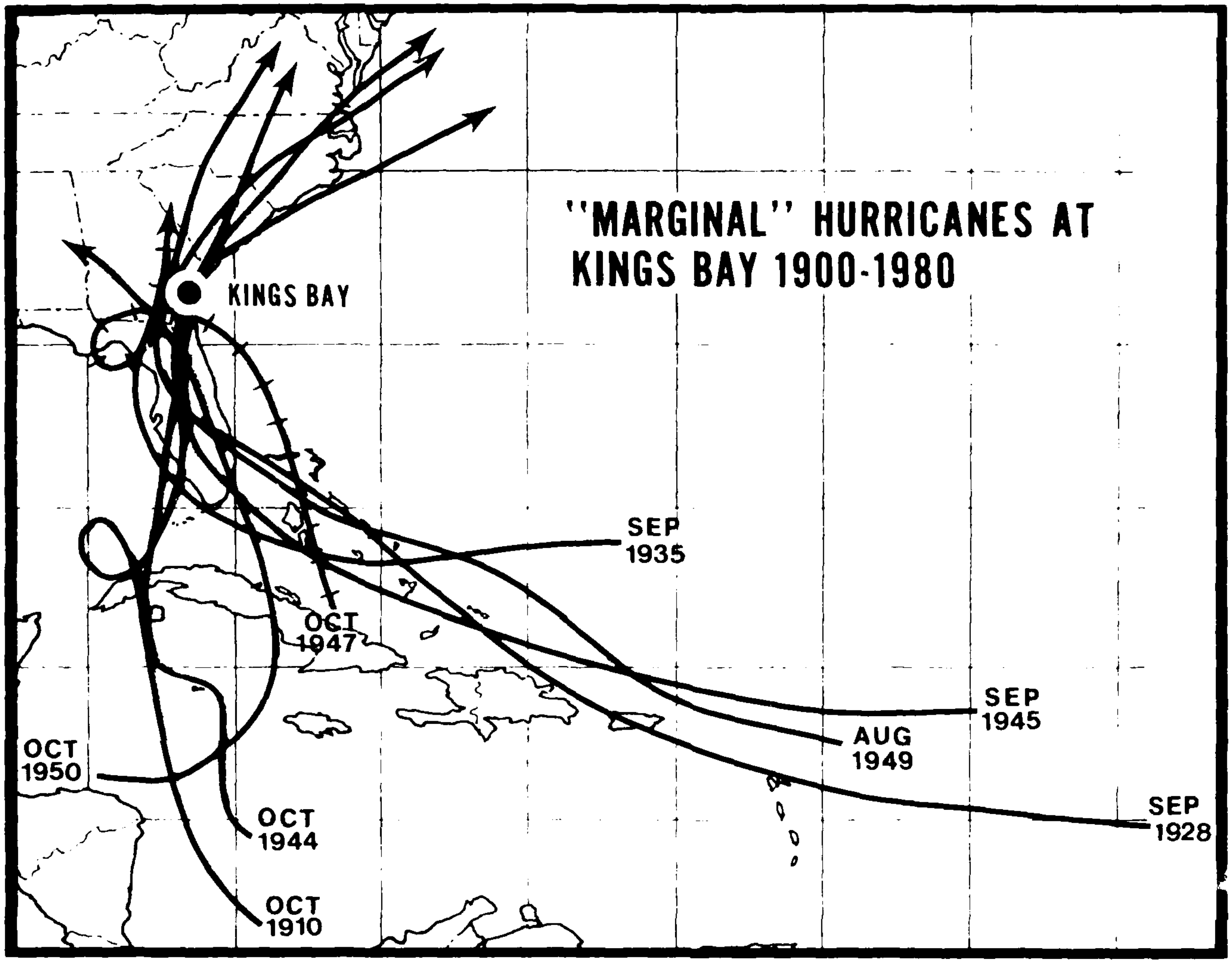

Figure VI-4. The eight tropical cyclones in the period 1900-1980 that produced sustained gale-to-storm-force winds of 34-50 kt (wind speeds estimated prior to 1944) at Kings Bay. The October 1974 storm (track with crossbars) did not reach hurricane intensity of 64 kt or greater, but had a pronounced impact at Kings Bay because of its nearby direct landfall. All eight tropical cyclones produced littoral effects -- combined effects of winds, waves, tides, and sediment transport -- that are judged as being "marginally unsafe" for the submarines and their tender at the Base. (See also Table VI-2.)

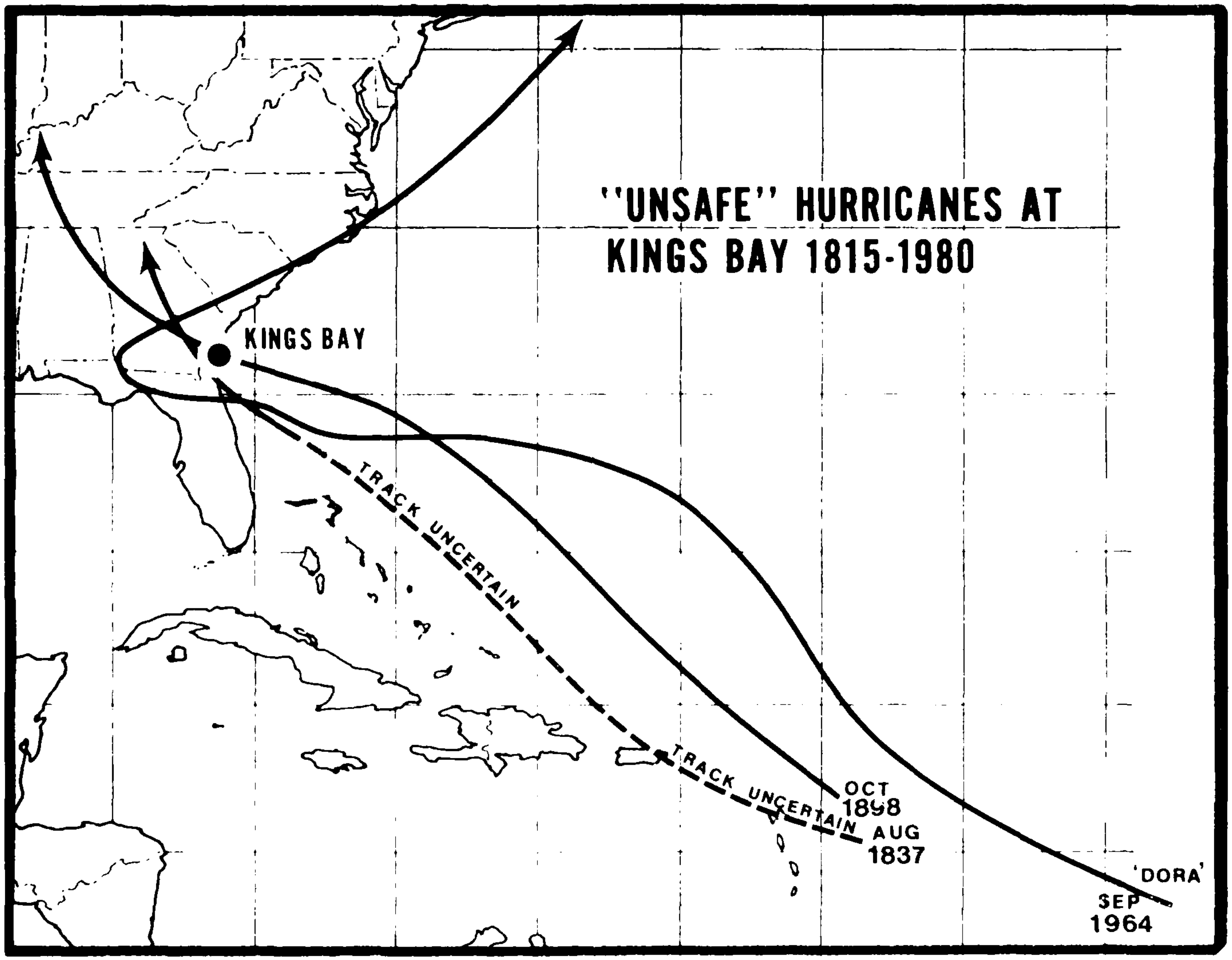

Figure VI-5. The three hurricanes in the period 1815-1980 that made a direct landfall sufficiantly close to Kings Bay to have generated destructive wind and tidal effects in the area. Direct measurements or anecdotal records indicate that all three were of full hurricane intensity at landfall and produced conditions judged "unsafe" for submarines and their tender at the Base. The effects of such hurricanes probably also would include massive shoaling at the St. Marys entrance. (See also Table VI-2.)

The average frequency of recurrence of sustained hurricane force winds at Kings Bay is estimated at once in 60 years. This compares favorably with Norfolk, Virginia for which hurricane force winds recur every 30 years on average. Destructive force winds (i.e., above 48 kt) probably recur at both Kings Bay and Norfolk with similar frequency every 10 years on average.

4.3 WAVE ACTION

Kings bay is well protected from both open ocean swell and also from wind waves generated in the deeper areas of the tidal sounds. Wave action caused by Hurricane Dora's landfall in 1964 only amounted to 2-ft waves at Kings Bay, according to an eyewitness account.

4.4 STORM SURGE AND TIDES

The exceptionally high water levels produced by the combined effects of the normal astronomical tide and the storm surge associated with a hurricane are illustrated in Table VI-1. The tide gauge at Fernandina Beach on the Amelia River appears to provide a good estimate of water levels at the Kings Bay waterfront, even under the exceptional conditions created by storm surge. The present wharf at Kings Bay extends to 8 ft above mean sea level and was close to being overtopped according to an eyewitness during Dora's passage in 1964, who noted that small waves (up to 2 ft) broke over the wharf. An additional tide gauge on the ocean shore at Fernandina Beach recorded a water level of 10 ft during Dora's passage. This difference in levels over the 1 1/2 mile width of Amelia Island provides an insight into the exceptional current which flowed through the St. Marys Entrance channel on the occasion and which displaced many of the channel markers.

Table VI-1. Exceptional tidal levels[2] recorded at Amelia River, Fernandina Beach during the passage of hurricanes.

Date	Height (Ft)	Remarks
6 August 1837	10 est.	Landfall 10 n mi south of Kings Bay
2 October 1898	10.8	Landfall 18 n mi north of Kings Bay
21 October 1906	5.6	Along shore <u>southwards</u> then landfall 100 n mi south of Kings Bay
11-18 October 1910	4.9	Overland approach, passed to west
19 October 1944	7.6	Overland approach, direct strike
7-9 October 1946	6.3	Overland approach, passed to west
15-19 October 1950	5.9	Overland approach, passed to west
9-10 September 1964	7.8	Landfall 30 n mi south of Kings Bay

[2]Levels refer to National Geodetic Vertical Datum of 1929 which does not incorporate local and temporal changes in sea level that have occurred since 1929. Data drawn from NOS Storm Evacuation Map T-15071 and other sources.

The 10.8 ft level at the Amelia River gauge on 2 October 1898 demonstrates the widespread flooding of the Kings Bay waterfront area which can be expected from the rare nearby landfall of a hurricane. Water levels on the ocean side of Cumberland Island were probably close to 15 ft on this occasion in which case, some overtopping of Cumberland Island south of Dungeness may have occurred (see Figure VI-1).

Table VI-1 also indicates that those hurricanes which made an overland approach toward Kings Bay produced less dramatic tidal effects, while only one of the many alongshore hurricanes is represented. This "alongshore" hurricane of October 1906 produced significant surge effects because of its southward movement off the Georgia/Florida coast. The more commonplace north-going alongshore hurricanes (e.g., David, 1979) do not produce significant tidal effects because of northerly track places their best surge-producing potential on the seaward side of the hurricane's eye. Note also that, apart from the unusual alongshore hurricane of 1906, all of the significant storm surge events listed in Table VI-1 correspond with those hurricanes depicted in Figures VI-4 and VI-5 which were designated "marginal" and "unsafe" on the basis of their wind effects at Kings Bay.

4.5 SHOALING OF DREDGED CHANNELS

Some concern has already been expressed in regard to both the gradual silting of the channels which give deep draft submarines access to Kings Bay as well as the possibility of sudden shoaling of these channels during the passage of a hurricane (Jenkins and Skelly, 1981). The author of this study has attempted to relate the incidence of emergency dredging events in the Kings Bay area, including ports with similarly dredged entrance channels further south (Jacksonville and Port Canaveral). Positive evidence of sudden shoaling during Hurricane Dora's landfall in 1964 was obtained (Turpin, 1981). It was necessary to dredge the entrance to both Port Canaveral and Jacksonville on an emergency basis after Dora's passage. Emergency dredging of the St. Marys Entrance was not called for, but heavy routine dredging of this channel was recorded later in the same year. In 1964 the draft of traffic through the St. Marys Entrance was typically less than half that of a Trident-armed nuclear submarine. It was concluded that under present conditions, a hurricane of Dora's proportions would cause such slumping and silting of the dredged entrance channel that emergency dredging would be required, to allow nuclear submarines continued access to Kings Bay. From 1964 to date no emergency dredging events associated with tropical cyclones[3] in this area (Port Canaveral, FL, to Brunswick, GA) could be identified. However, during this period four hurricanes of the proportions of David, 1979, have affected Kings Bay (see Figure VI-3). Unfortunately, no hurricane events of the status of those "marginal" threat events depicted in Figure VI-4 have occurred during this period.

It is necessary, therefore, to conclude that while tropical cyclone threats characterized by those in Figure VI-3 will not lead to sudden shoaling, those characterized in Figure VI-4 may produce shoaling.

[3]A winter storm in October 1974 caused the closure of Port Canaveral, FL as a result of sudden shoaling of the entrance channel.

5. THE DECISION TO EVADE AT SEA OR REMAIN IN PORT

5.1 THREAT ASSESSMENT

In the foregoing analysis of the impact of tropical cyclones on the Kings Bay area, wind, wave, tidal and sudden shoaling effects were examined separately. Furthermore, by ranking storms according to their wind effects alone (Figure VI-3 through VI-5), it was later shown that their impact in terms of storm surge and shoaling, followed the same rank order. Wind and storm surge limits, regarded as "safe", "marginal" and "unsafe" for Navy vessels at Kings Bay are proposed in Table VI-2. The associated likelihood of sudden shoaling at the entrance channel is estimated as shown.

Table VI-2 Proposed wind and storm surge limits to define "safe", "marginal" and "unsafe" conditions for submarines and their tender at Kings Bay, GA. There is a close correspondence between these categories of environmental conditions and the three groups of tropical cyclones depicted in Figures VI-3, -4 and -5 respectively.

Environmental Effect	"Safe"	"Marginal	"Unsafe"	Benchmark
Wind at Kings Bay Max Sustained Speed (Kt)	Up to 33	34-50	Above 50	Overstress of S/M tender mooring
Storm Surge at Amelia River (Height in feet above MSL excluding effect of astronomical tide)	Less than 5	5-7	8-10	Inundation of Kings Bay waterfront area
Associated likelihood of sudden shoaling	Highly Improbable	Possible (no cases available to date)	Highly Probable	Shoaling of St. Marys Entrance to less than draft of surfaced S/M

These guidelines in Table VI-2 are difficult to apply to specific tropical cyclones. Fortunately, it is possible to relate a tropical cyclone's forecast intensity and the broad features of its forecast track to its destructive impact at Kings Bay as follows:

(1) "<u>Direct Landfalling</u>" hurricanes (see Figure VI-5) originating in the tropical or subtropical Atlantic Ocean east of the Bahamas which subsequently approach over the warm ocean current just north of the Bahamas, can create UNSAFE conditions at Kings Bay within the following limits:

- (a) Actual or forecast hurricane intensity prior to landfall.
- (b) Landfall along the Florida/Georgia coast within 90 n mi south or 30 n mi north of St. Marys Entrance.

(2) "<u>Direct Landfalling</u>" tropical cyclones which are not forecast to reach hurricane intensity prior to landfall (e.g, Oct 1947 storm in Figure VI-4) can create MARGINAL conditions at Kings Bay within the following limits:

- (a) Actual or forecast <u>SEVERE</u> storm intensity (50 to 63 kt) prior to landfall.
- (b) Landfall along the Florida/Georgia coast within 60 n mi south or 20 n mi north of St. Marys Entrance.

(3) "Overland" hurricanes (see Figure VI-4) originating in either the west Caribbean Sea or the tropical or subtropical Atlantic Ocean can create MARGINAL conditions at Kings Bay within the following limits:

(a) Actual or forecast hurricane intensity at point of initial landfall.

(b) Forecast closest point of approach (CPA) between 60 n mi west of Kings Bay and a direct strike.

(4) "Alongshore" hurricanes which pass close to, but do not make a landfall in the Kings Bay area (e.g., Hurricane David, 1979 - depicted in Figure VI-3), have remarkably little impact at Kings Bay. Such hurricanes create conditions at Kings Bay which are considered to be SAFE within the following limits:

(a) Actual or forecast intensity - no limit.

(b) Forecast closest point of approach OUTSIDE 20 n mi east of Kings Bay (i.e., at least 18 n mi offshore).

5.2 SUMMARY OF SORTIE CRITERIA

Sortie of all ocean-going Navy units is recommended for all tropical cyclone threats judged to be MARGINAL or UNSAFE in Section 5.1 above. Typically these include the following:

(1) All "direct landfalling" threats when expected to reach severe storm intensity (50-63 kt) or hurricane intensity (64 kt or above) before landfall.

(2) All "overland" threats when full hurricane intensity (64 kt or above) at initial point of landfall is expected and forecast track implies a direct strike or close pass to the west of Kings Bay.

Numerous threats from tropical cyclones can be expected at Kings Bay for which sortie of Navy units is difficult to justify. Typically these include the following:

(1) "Overland" threats from tropical cyclones forming in the Gulf of Mexico and exiting along the east Florida or Georgia coasts.

(2) "Overland" threats from tropical cyclones forming in the west Caribbean early in the hurricane season (May and June).

(3) "Overland" threats from all sources which exit along the east Florida coast south of the St. Marys Entrance (and subsequently behave as "Alongshore Hurricanes").

(4) "Alongshore" hurricanes.

(5) Any tropical cyclone forming within 300 n mi of Kings Bay.

5.3 EVASION AT SEA

If current tropical cyclone forecasts in conjunction with the guidelines in Section 5.1 point to sortie action by the submarines, their tender and any large visiting surface units, the tactics given below are recommended.

5.3.1 Submarines

A direct course at best speed to safe submergence depth is appropriate to all circumstances of the tropical cyclone threat, provided that sortie is executed sufficiently early to avoid the surfaced transit being hampered by high

sea states. Note that a hurricane threatening direct landfall in the Kings Bay area is likely to be moving north of the Bahamas along a reciprocal course to your transit to deep water. The decision to sortie in this case must be taken especially early to avoid high sea states prior to submergence.

5.3.2 Surface Vessels

Evasion tactics recommended for vessels sortieing from Mayport, FL apply (see Paras. 5.1 and 5.3 of Section V). The main principles are as follows:

(1) North Atlantic hurricanes north of the Bahamas: If these threaten to make landfall in the Kings Bay area early departure is imperative to establish plenty of sea room either to the south or north of its track. Evasion southwards to the Straits of Florida is recommended for storms forecast to remain north of a true bearing of 110 from the St. Marys Entrance. Evasion east or northeastwards is recommended for storms forecast to remain south of this bearing.

(2) North Atlantic hurricanes south or west of the Bahamas: Evasion east-southeastwards is recommended.

5.4 SECURING SUPPORT VESSELS AND SUBMARINES UNDER REPAIR

The possibility of exceptionally high tides caused by storm surge accompanying a hurricane strike carries a threat of damage to shallow draft support craft if they are secured alongside the wharf as shown in Figure VI-2. Both the tugs and floating crane were unscathed after being secured in this manner after Hurricane David's pass offshore in 1979. However, a direct strike, or near pass to the west of Kings Bay would have produced a different result.

The moorings laid in the upper bay (northwest of the existing wharf) are so substantial (40,000 lb anchors with 75 ft of 3" chain) that they would prove ideal hurricane moorings for support vessels despite poor holding ground.

Submarines under repair in the floating dock (ARDM) southeast of the wharf (see Inset, Figure VI-1) may not be capable of completing preparations to sortie in the short time scale of a hurricane warning. The dock itself presents a large sail area which, despite the rigidity of the "spud" mooring that secures the dock to its concrete pier, would lead to some buffetting motion during high winds which would be communicated to any vessel under repair inside. Therefore safeguarding the docked submarine may call for extra attention to its support inside the dock. Moreover, if the watertight integrity of the docked submarine can be reestablished, then there is some further advantage in flooding the dock down to reduce its sail area.

The hurricane-proof properties[4] of the "spud"-moored floating dock also present the possibility of using it to safeguard many of the Base's auxiliary vessels if no submarine is occupying it.

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[4]Vertical tracks on the otherwise rigid "spud" mooring allow 20 ft of vertical motion relative to the pier which would easily accommodate storm surge effects and the mooring is expected to withstand 150 kt winds with the dock engaged.

5.5 RETURNING TO KINGS BAY

A tropical cyclone threat sufficiently serious to merit the sortie of Navy units to the open ocean from Kings Bay is likely to have caused some displacement of channel markers and perhaps sudden shoaling of the St. Marys Entrance or other dredged areas. Extra navigational precautions should be taken by returning vessels.

6. FUTURE DEVELOPMENT OF THE BASE

The design of new wharves, docks and other shore facilities has taken full account of the winds and exceptionally high tides which may be associated with a hurricane strike. However, there are inevitable by-products of the planned expansion which could affect the Base's vulnerability to a hurricane threat, depending upon the phasing of the growing facilities. First, for example, expansion into the upper bay may require the loss of existing upper bay moorings at a time when the number of support vessels is increasing. This would create difficulties in safeguarding auxiliary vessels at the base during a hurricane threat. Second, further overdredging of approach channels to accommodate deeper draft submarines may be required before corresponding improvements in emergency dredging facilities (to counteract the increased sensitivity of these channels to storm-induced slumping) can be made. Third, the low-level sheltering of assets both ashore and afloat will be strongly influenced by the manner in which local forest is preserved. Consideration may even be given to planting suitable species of shrub or tree on Crab Island to improve shelter from this direction and stabilize the island's topsoil against heavy silting of the main channel in the event of storm tides. Note that shelter provided by afforestation is far more effective in protecting the base area from destructive winds than raising solid barriers of a similar height. This stems from the importance of aerodynamic roughness of the environment in absorbing the kinetic energy of the wind in the generation of mechanical turbulence. Even tall pine trees proved effective in hurricane force winds, created by the landfall of Hurricane Frederic, in safeguarding mobile homes from damage in Mississippi in 1979 (Fujita, 1980).

Future developments at Kings Bay may influence the impact of a hurricane threat on submarine operations based on both Kings Bay and Port Canaveral. This is most likely when both locations are threatened by the same hurricane. In this event, seaworthy submarines from both Bases may sortie. However, after successful evasion at sea, they may be confronted with the closure of, or reduced facilities at, either location. The phasing of developments in emergency dredging facilities in the area and more especially, the ability of Kings Bay and Port Canaveral to offer mutually compatible emergency facilities to submarines operating from both locations, will affect the security of submarine operations in the face of meteorological and other hazards.

The projected graving dock facility will provide ideal hurricane berthing for auxiliary vessels if it is not occupied by a submarine water repair at the time of the hurricane threat.

7. ADVICE TO SMALL CRAFT

Vessels too large to be secured ashore against a hurricane threat should secure in those reaches of the principal rivers which are sheltered from the south and east by wooded high bluffs. Examples[5] are Mush Bluff on Crooked River and the bluffs 4 miles above St. Marys on the St. Marys River. Numerous small creeks possessing shelter from adjacent woodlands also exist. Such hurricane holes should be prospected before a hurricane threat. Advice on the method of securing small craft to trees in sheltered creeks and waterways is found in the Coast Pilot 4 (1979), Cape Henry to Key West as follows:

> Hurricane Moorings - small boats should seek shelter in a small winding stream whose banks are lined with trees - preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches, having more give, will ease shocks in gusts.

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[5]These examples of hurricane holes are located at "A" and "B" on Figure VI-1.

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VII: CONTENTS

VII. MOREHEAD CITY, NORTH CAROLINA

SUMMARY

Morehead City's south-facing aspect on the marshy promontory of North Carolina exposes it to the onslaught of many recurving tropical cyclones in the North Atlantic, against which it poses a low, slender island barrier. The port's vulnerability to destructive force winds and under certain circumstances, destructive tidal effects, makes it unsuitable as a hurricane haven for both small craft and large ocean-going vessels. Therefore, the emphasis of this study is on the analysis of factors governing the impact of tropical cyclones at Morehead City. The guidelines from this analysis can be used in conjunction with real-time forecasts to improve the quality of the stay/leave decision in the event of a tropical cyclone threat.

There are no sheltered berths or hurricane anchorages for deep draft vessels. These vessels should sortie if hurricane force (64 kt or above) winds are expected. Vessels with a large sail area, such as LPHs, LHAs or large bulk carriers, should sortie if winds of 48 kt or more are expected.

Recommendations for assessing the threat posed by a particular tropical cyclone are presented in the text together with a rationale for choosing appropriate evasion tactics at sea. Advice is offered to masters of deep draft vessels unable to sortie together with recommendations for securing smaller craft against a hurricane threat.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

Morehead City lies behind a long, slender island barrier which separates the marshy lowlands of eastern North Carolina from the Atlantic Ocean between the border with Virginia in the north and Wilmington in the south (Figure VII-1). Numerous breaks exist in this barrier, through which estuarine and tidal currents flow in response to changes in the levels of the sheltered sounds or the ocean outside. Figure VII-2 shows the position of Beaufort Inlet through which channels are maintained by dredging (Figure VII-3) to provide deep draft vessels access to the commercial port of Morehead City. A subsidiary dredged channel allows fishing vessels and recreational craft to reach the port of Beaufort. The intracoastal Waterway reaches Morehead City from the west via Bogue Sound, then turns north to reach the Neuse River via Adams Creek Canal (Figure VII-2).

This hurricane haven evaluation was prepared by LT CDR R.J.B. Turpin, RN, Royal Navy Exchange Officer at NAVENVPREDRSCHFAC.

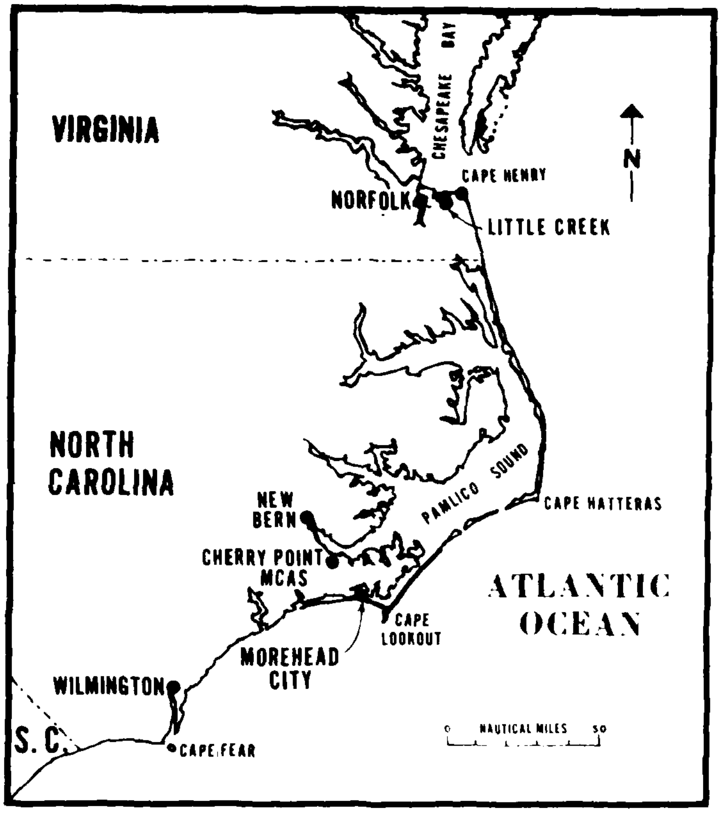


Figure VII-1. Locator map for Morehead City, NC. Coastal features include extensive barrier islands and associated sounds which separate the marshy coastal plain from the open ocean.

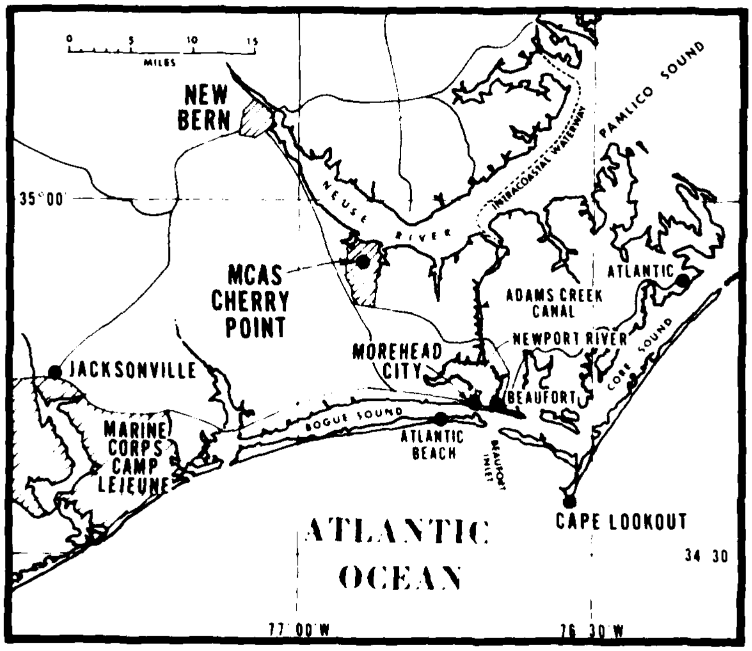


Figure VII-2. Military and civil facilities in th Morehead City vicinity. Access to the Morehead City and Beaufort port facilities from the open ocean is via Beaufort Inlet, a breach in the barrier island just east of Morehead City.

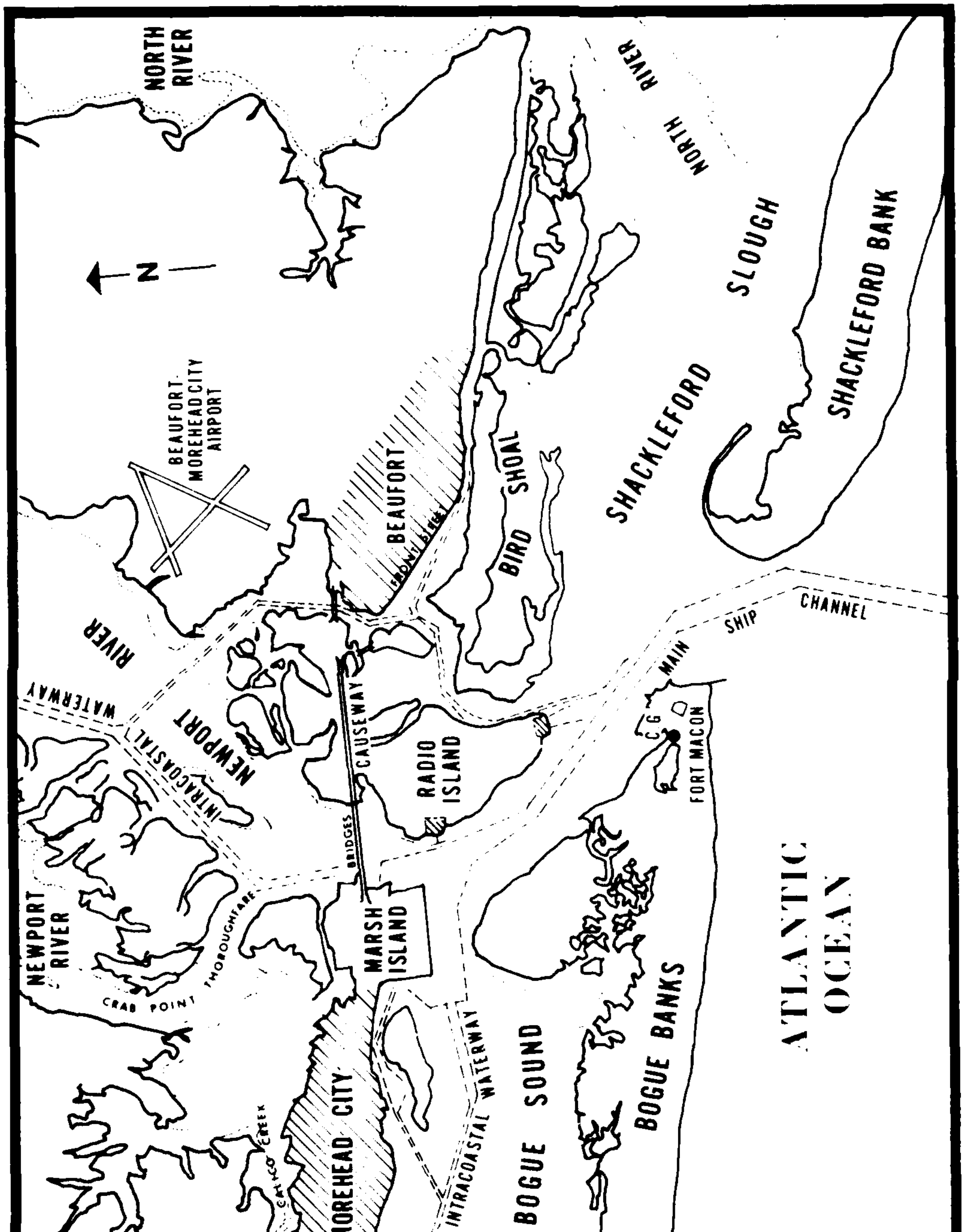


Figure VII-3. Configuration of the dredged channels and natural sounds linking the port facilities north of the barrier island (shown here as Bogue and Shackleford Banks) with the open ocean and Intracoastal Waterway.

Morehead City, Radio Island and Beaufort are linked by road and rail bridges (Figure VII-3) which straddle a large marsh to the north of Radio Island, either side of which lie the dredged channels leading northwards from each port through the shallow sound of the Newport River to Adams Creek Canal (Figure VII-2).

There is a confluence of drainage currents from the sheltered sounds surrounding Morehead City at Beaufort Inlet. (See Chart 11545 Beaufort Inlet and part of Core Sound.) Dredging effort broadly follows the resulting pattern of natural channels. Large tracts of the sounds are nevertheless very shallow - which reflects the low elevations of the marshy coastal hinterland. The average elevation of all the land to the east of Adams Creek Canal is below 10 ft above mean sea level and major flooding of Morehead City and Beaufort would occur at water levels of 6 ft above MSL (i.e., only 2 to 3 ft above astronomical Spring High Tide).

The topography of the barrier island south of the port, Bogue Banks, is similar to the mainland but is considered to provide some protection at Morehead City and Beaufort against the combined effects of storm tides and wave action (see Section 3). Seaward of Bogue Banks, there extends a broad continental shelf over which the central core of the Gulf Stream flows roughly parallel with the 100 fathom depth contour, 55 miles south of Beaufort Inlet (Chart 11009 Cape Hatteras to Straits of Florida).

For further details see the following Charts:

Chart 11009 Cape Hatteras to Straits of Florida

Chart 11544 Portsmouth Island to Beaufort including Cape Lookout Shoals

Chart 11543 Cape Lookout to New River.

Chart 11545 Beaufort Inlet and Port of Core Sound

Chart 11547 Morehead City Harbor

2. THE HARBORS AND THEIR FACILITIES

Figure VII-3 provides an overview of berthing facilities in the Morehead City/Beaufort area. The only Navy-owned facilities are 3 LST ramps and a large paved staging area at the southern tip of Radio Island. Commercial traffic includes deep draft vessels (container, general and bulk cargo), Intracoastal Waterway traffic and the menhaden fishing fleets. Deep draft vessels berth at the State Port Terminal, Marsh Island, Morehead City and the privately-owned Aviation Fuel Terminal on Radio Island. Intracoastal Waterway vessels also berth at Marsh Island, north of the road and rail bridges at the barge facility (see Figure VII-4). The menhaden fishing fleets occupy berths along the Front Street foreshore at Beaufort. U.S. Coast Guard vessels berth at their Fort Macon Base at Beaufort Inlet.

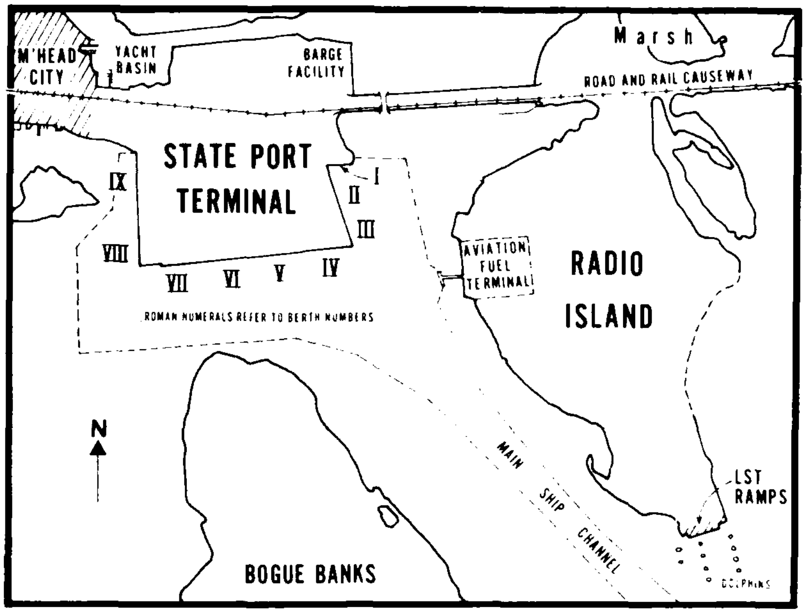


Figure VII-4. Deepwater berths at the State Port Terminal, Morehead City; and the Aviation Fuel Terminal, Radio Island. The approach to the LST ramps, Radio Island, is maintained at a depth of 16 feet.

Navy use of the port centers on the embarking and debarking of Marine Corp elements based at Camp Lejuene and Cherry Point (see Figure VII-2). The Navy-owned LST ramps at Radio Island are for this purpose (see Figures VII-3 and VII-4). Additionally, by prior arrangement through the Naval Port Control Office with the management of the State Port Terminal, visiting Navy ships may also use deep water berths or the state-owned LST ramps at the terminal (see Figure VII-4). The latter are rarely used due to awkward approaches for vehicles. Deep water berths II through IX are used for loading Navy amphibious ships. Vessels operated by or chartered to the Military Sealift Command berth at the Aviation Fuel Terminal on Radio Island. Finally, small Navy craft may also use the Marsh Island barge facility north of the bridges. Apart from the activities of Military Sealift Command ships, all matters concerning Navy use of the port are the responsibility of the Officer-in-Charge, Naval Port Control Office under the direction of the Commanding Officer, Naval Amphibious Base, Little Creek. Further details may be found in the following publications:

U.S. Coast Pilot 4, Atlantic Coast: Cape Henry to Key West

DMA Hydrographic/Topographic Center Publication 940 Chapter 14, Fleet Guide, Morehead City, North Carolina

Recreational craft abound in the area. At Morehead City, charter vessels for sport fishing and other small craft berth along the south foreshore west of the State Port Terminal. There is a yacht basin on the north shore. Other small craft facilities (e.g., at Peletier and Spooners Creeks) lie along the Intracoastal Waterway in Bogue Sound to the west of the city and also at the north of Radio Island to the east of the city. Beaufort has undergone considerable waterfront redevelopment to provide improved facilities for visiting yachts. The southwest waterfront adjoining Front Street provides alongside berthing and anchorage in the basin. A complete tabulation of the services and supplies available to small craft in the area is included in Chart 11541 "Neuse River to Myrtle Grove Sound."

2.1 HEAVY WEATHER FACILITIES

In relation to the needs of deep draft vessels, these facilities are very limited. There are no sheltered anchorages. Commercial tug power consists of 4 tugs ranging in size from 350 to 1400 h.p. and is not considered to be adequate for the needs of the Tarawa Class Navy amphibious assault ship for whom additional Navy tugs should be requested prior to a visit to the port (see Fleet Guide, Morehead City). No drydocking facilities for ocean-going vessels exist locally. The nearest facilities for major repairs to Navy and commercial vessels are at Norfolk and Newport News. Hurricane hawsers and fenders cannot be provided by the port.

During a tropical cyclone threat, commercial vessels should maintain liaison with the Coast Guard and State Port Management. Navy units should additionally liaise with the OIC, Naval Port Control Office who is SOPA (ADMIN).

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT MOREHEAD CITY

3.1 INTRODUCTION

The following analysis provides an assessment of the impact of tropical cyclones at Morehead City in terms of their effects of winds, wave action and in particular, the associated storm tides and currents.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Morehead City is considered to have been a threat to the port. Similar studies in the Pacific Ocean have shown this radius to include the majority of tropical cyclones which have produced operationally significant

weather effects. The analysis of storm movement relative to the port concentrates on the period 1871 to 1980 for which detailed track data are available (Newmann et al., 1978). Data on winds and storm tides at Morehead City are limited and recourse has been made to records for neighboring locations in order to infer the impact of these phenomena at the port.

3.2.1 Formation, development and movement

During the period 1871 to 1980, an average of 1.8 tropical cyclones per year have passed within 180 n mi of Morehead City. The climatology of their formation, development and movement can be summarized as follows:

(1) Formation: Morehead City does not lie in a vigorous formation area. Records for the period 1871 through 1980 show only 4 tropical depressions forming within 180 n mi of the port, none of which reached hurricane strength within this range of Morehead City.

(2) Development: Although the development of tropical depressions depends upon the interaction of many factors, records of their movement and intensity this century indicate that no tropical or subtropical depression which formed within 300 n mi of Morehead City reached hurricane force while its track remained within this range of the port. The principal threat to Morehead City is from tropical depressions which have formed well outside this radius to the south or southeast of the City and have made the last 300 n mi of their approach over water.

(3) Movement: Morehead City has a latitude just short of 35°N and as most tropical cyclones in the North Atlantic undergo recurvature between 25 and 35°N (Cry, 1965) it follows that those which pass close to the port are mostly in the process of recurvature or have already recurved on to a northerly or northeasterly track. Figure VII-5 displays the direction of approach towards Morehead City of all tropical cyclones which passed within 180 n mi of the port from 1871 to 1979. More than half of these entered the 180 n mi range circle from the south or southwest octants. Beyond the 180 n mi circle these tropical cyclones divide into two major families:

(a) Those originating in the main basin of the North Atlantic which approach over water from the south or southeast.

(b) Those originating in the west Caribbean or Gulf of Mexico, most of which are subsequently weakened by the overland segment of their approach from the southwest or west.

This division is illustrated in Figure VII-6 in which these two principal threat axes are superimposed upon a series of envelopes expressing the annual % probability of a tropical cyclone passing within 180 n mi of Morehead City. The shape of the 20% probability envelope also suggests this division. The

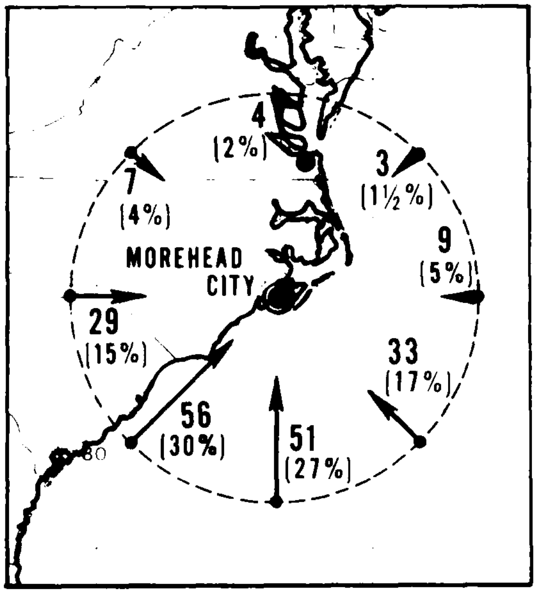


Figure VII-5. Direction of approach toward Morehead City of tropical cyclones that passed within 180 n mi of the port during the period 1871-1979. Numerals show total number of storms that approached in each octant; percentages in () show % of total.

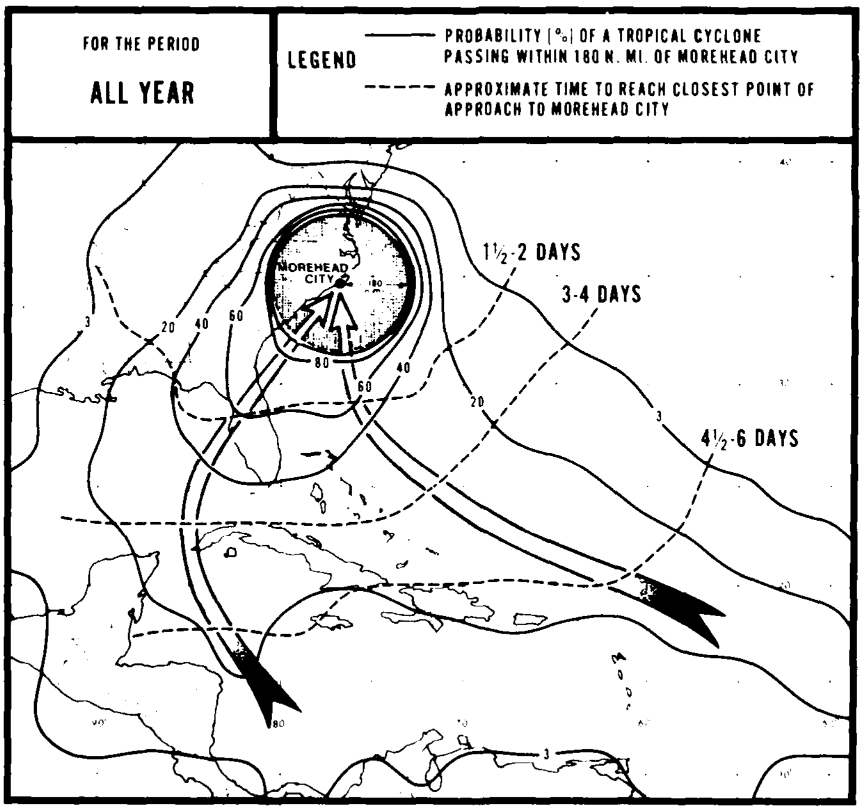
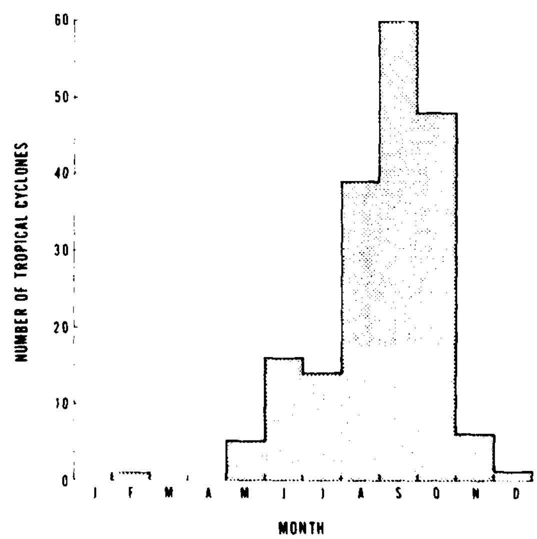


Figure VII-6. Annual probability that a tropical cyclone will pass within 180 n mi of Morehead City (based on data from 1871-1979). Shapes of near-pass-probability envelopes derive from two distinct families of storm tracks centered on the arrows; each group's relative importance varies throughout the hurricane season (see Figures VII-8,-9,-10,-11).

separation of these two families of threat storms is more clearly evident when seasonal changes in storm movement are considered (see below). The dashed lines of Figure VII-6 indicate the average time a storm takes to reach its closest point of approach (CPA) to the port. The spacing of these dashed lines displays the well established deceleration of storms during recurvature and their subsequent acceleration along tracks with an easterly component after recurvature.

(4) Seasonal Effects: The tropical cyclone season at Morehead City extends from May to November with peak activity in September as Figure VII-7 shows. The seasonal changes in geographical areas of formation and movement of storms which threaten the port can be visualized from the changing shape of the near-pass probability envelopes in the series: Figure VII-8 through VII-11. Figure VII-8 (January through June) shows that most early season threat storms form in the west Caribbean and Gulf of Mexico, make landfall on the Gulf coast and subsequently follow either overland or over-water tracks toward Morehead City. Figure VII-9 (July/August) displays an abrupt swing of the threat axis toward the main basin of the tropical and subtropical North Atlantic Ocean. Figure VII-10 (September) reveals some revival in the threat from storms emerging from the Gulf of Mexico and Caribbean. Finally Figure VII-11 (October through December) displays a late season pattern which, in the predominance of the threat from the Caribbean and Gulf of Mexico, closely resembles the early season situation depicted in Figure VII-8 (January through June).

Figure VII-7. Seasonal distribution of tropical cyclones passing within 180 n mi of Morehead City during the period 1871-1979.



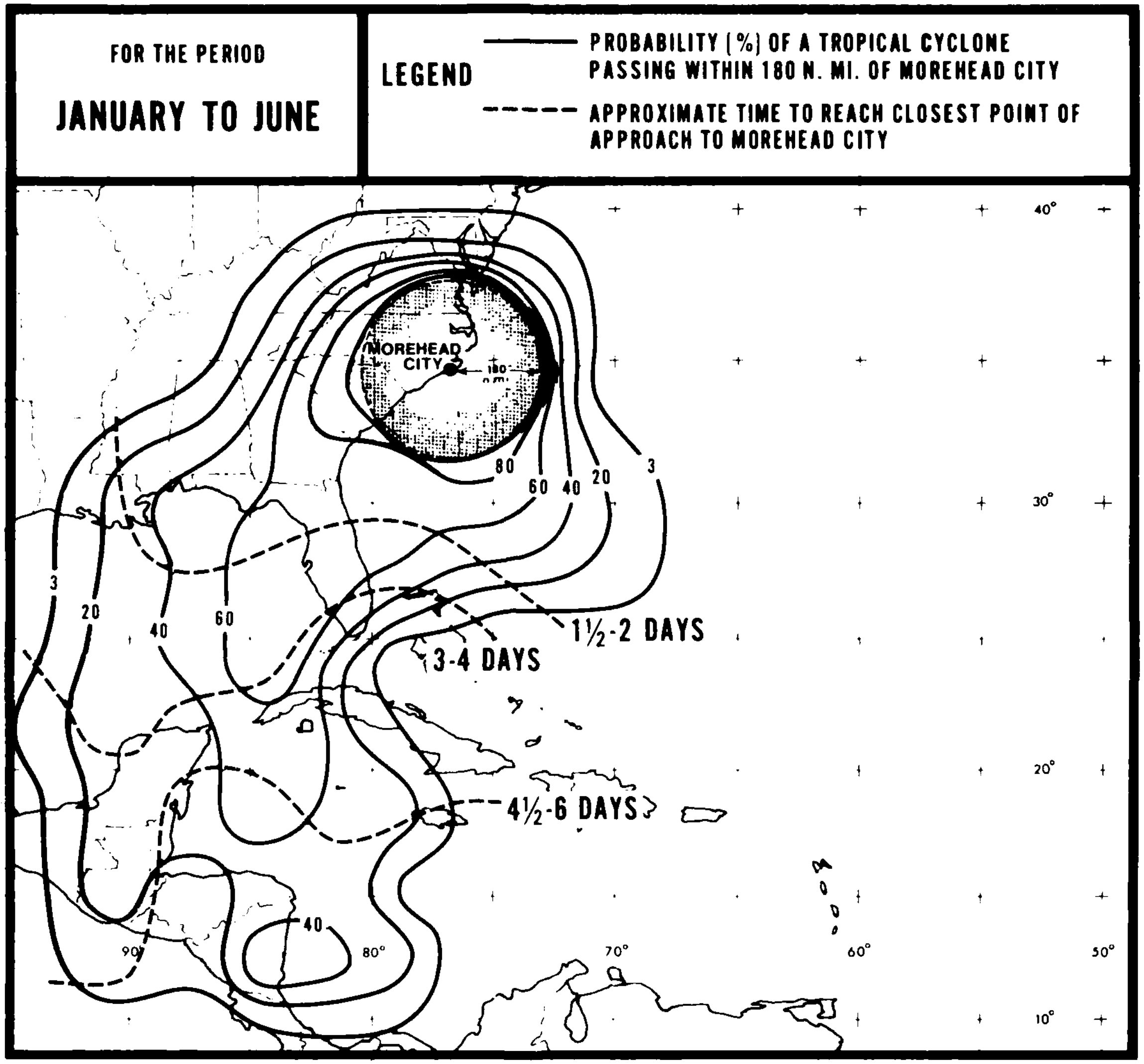


Figure VII-8. Probability that a tropical cyclone will pass within 180 n mi of Morehead City during the period January-June (based on data from 1871-1979). Shapes of near-pass-probability envelopes early in the hurricane season show a strong bias toward storms originating in the west Caribbean Sea or Gulf of Mexico.

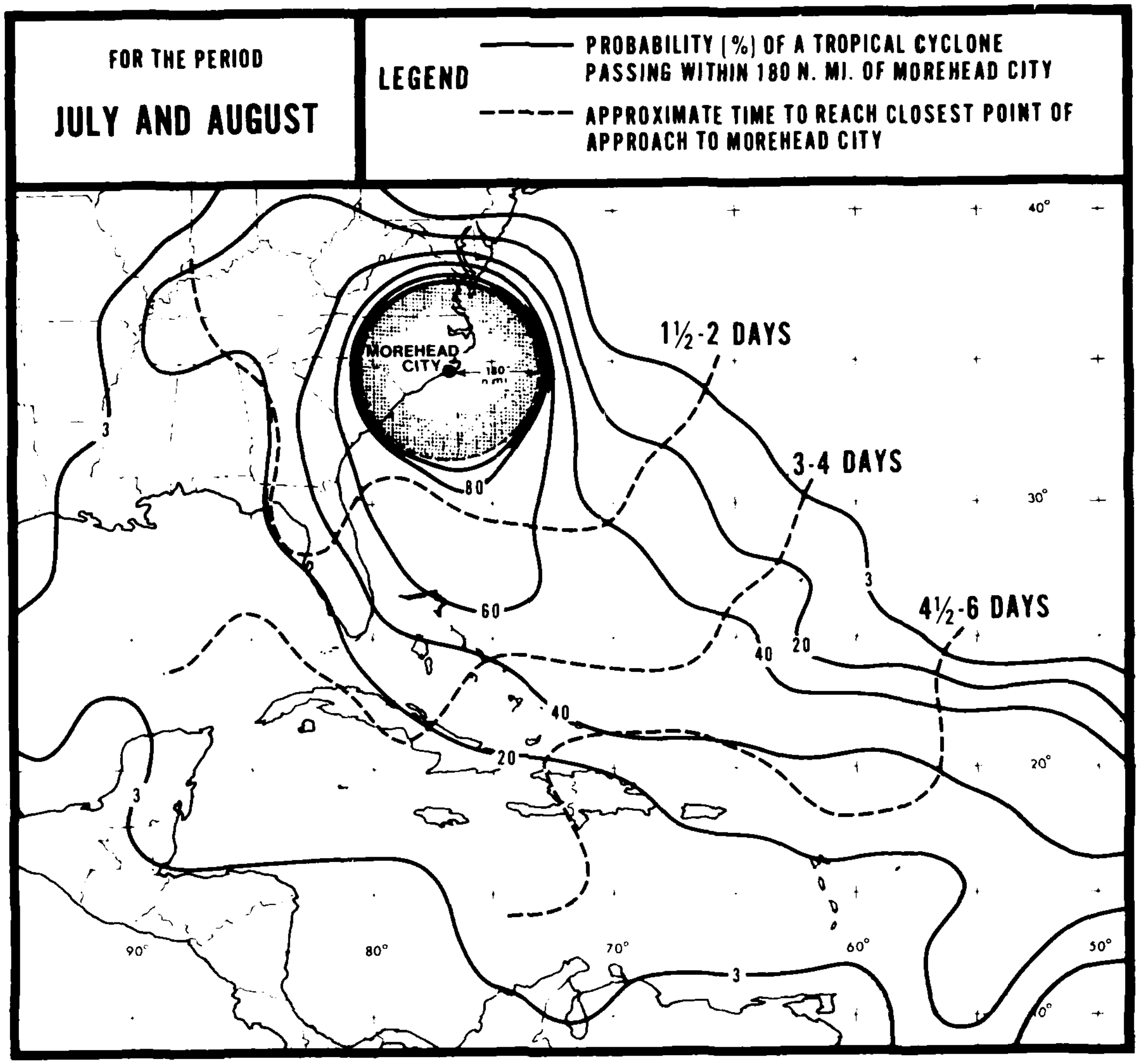


Figure VII-9. Probability that a tropical cyclone will pass within 180 n mi of Morehead City during July and August (based on data from 1871-1979). Compared to January-June, near-pass-probability envelopes for July and August show a decisive switch eastward toward tropical cyclones originating in the main basin of the tropical and subtropical Atlantic Ocean. Dashed lines of times to CPA show marked dips at their western extremes, relating to accelerations of those storms that have completed recurvature.

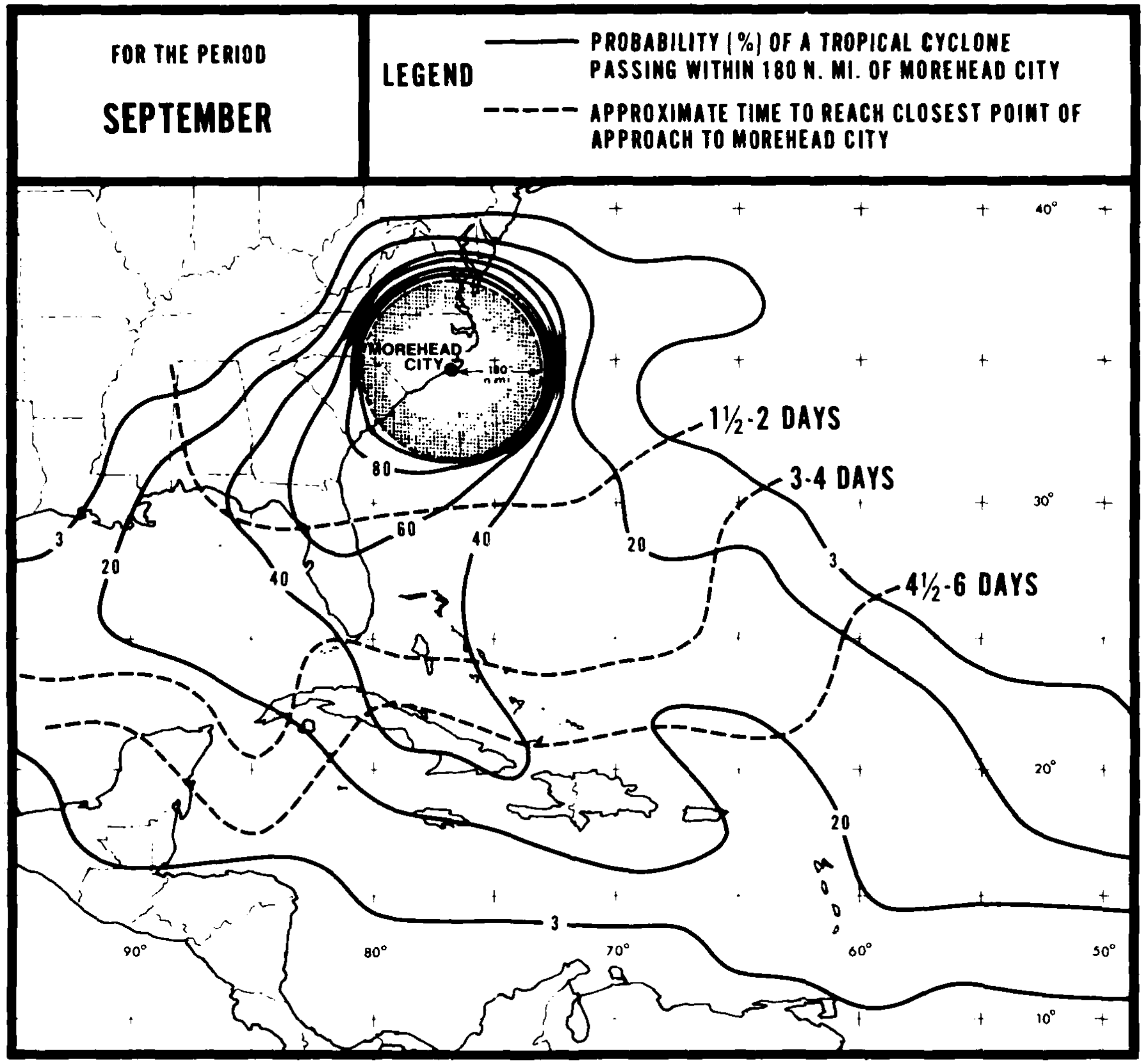


Figure VII-10. Probability that a tropical cyclone will pass within 180 n mi of Morehead City during September (based on data from 1871-1979). Compared to July-August, near-pass-probability envelopes for September show a swing back toward storms originating further west. The main threat of potential damage at Morehead City in September, however, remains with vigorous storms that follow the more easterly overwater track through the main Atlantic basin.

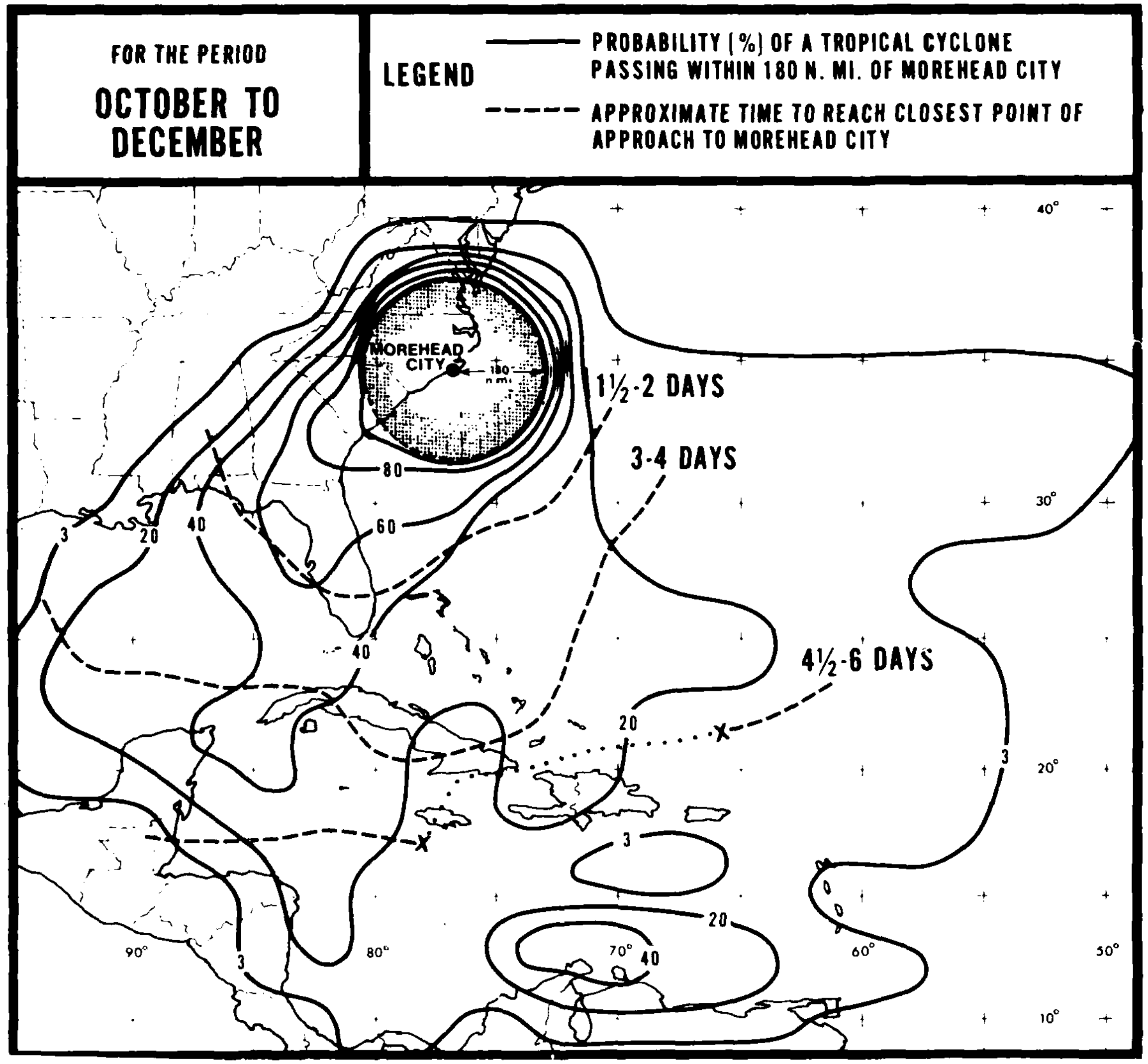


Figure VII-11. Probability that a tropical cyclone will pass within 180 ni mi of Morehead City during October-December (based on data from 1871-1979). The September trend, more numerous threats from storms originating west of the main Atlantic basin, continues into October-December. The main threat of potential damage at Morehead City late in the season is from storms that originate in the Caribbean and enter the main Atlantic basin with minimal overland transit (see Figure VII-12).

3.2.2 Winds

A detailed scrutiny of the history of winds at a port during the near-pass or strike of tropical cyclones is an important element in evaluating its haven properties. Unfortunately, the meteorological history of Morehead City is poorly documented. The nearest station for which hourly synoptic data is available lies approximately 20 miles to the northwest at the Marine Corps Air Station (MCAS), Cherry Point (see Figures VII-1 and 2). This airfield lies in a clearing within dense pine woods of the Croatan National Forest and is less exposed than the marshy coastal site of Morehead City. However, by assembling the rather patchy data from nearby exposed sites, it has been possible to deduce the maximum winds at Morehead Ci during the passage of all tropical cyclones passing within 180 n mi of t port from 1945 to 1979. The results are compared in Table VII-1 with the maximum winds for each storm recorded at Cherry Point MCAS.

Although no simple relationship exists between the maximum winds at Cherry Point and Morehead City during tropical cyclone passes, there is a close identity between those storms which produce the stronger winds at each of these locations. For example, the complete tracks of the eleven tropical cyclones giving winds of 34 kt or greater at MCAS Cherry Point from 1945 to 1980 depicted in Figure VII-12, embrace all five tropical cyclones which caused sustained winds of hurricane force (64 kt) or greater at Morehead City and 10 out of the 12 which produced destructive force (48 kt) winds or greater at the port. Figure VII-12 therefore characterizes those tropical cyclones with a powerful impact in terms of wind at Morehead City. Note the predominance of storms originating in the tropical Atlantic Ocean east of the Caribbean Sea among those causing hurricane force winds at the port.

Figure VII-13 displays segments from the tracks of those 21 tropical cyclones which produced winds of 22 kt or greater at MCAS Cherry Point. The beginning and end of each track segment shows the storm's position at the onset and cessation of 22 kt winds or greater at the Air station with an additional broken segment indicating the onset and cessation of 34 kt winds or greater. Table VII-1 suggests an association between 22 kt winds at Cherry Point and gale force winds at Morehead City, which would imply the possibility of harbor operations being hampered while an approaching tropical cyclone was as much as 250 miles away according to Figure VII-13.

Figure VII-13 does not imply a strong bias in the passing side of those tropical cyclones that produced significant winds at Morehead City. There is some clustering of storms passing close to the southeast and an associated predominance of north and northeasterly winds in Table VII-1. In view of the uncertainties in windspeed estimates at the port, no detailed analysis of the

Table VII-1. Comparison of maximum winds recorded at MCAS Cherry Point with estimated (E) or recorded (R) maximum winds at Morehead City during passage of all tropical cyclones that passed within 180 n mi of the port during the period 1945-1979.

TROPICAL CYCLONE		MAXIMUM WINDS (KT) DURING TROPICAL CYCLONE PASS			
		MCAS CHERRY POINT		MOREHEAD CITY	
Name/No.	Date	Sustained Wind (1 Min) Direction/Speed	Peak Gust	Sustained Wind (1 Min)	Peak Gust
9	Sep 1945	120/21	[illegible]	[illegible]	-
1	Jun 1945	300/30	41	[illegible]	-
6	Nov 1946	070/30	[illegible]	25(E)	-
5	Oct 1946	050/19	[illegible]	[illegible]	-
2	Jun 1946	200/22	30	30(E)	-
8	Oct 1947	010/34	41	[illegible]	-
6	Sep 1947	[illegible]	42	[illegible]	-
9	Nov 1948	250/14	-	[illegible]	-
3	Aug 1948	040/18	-	[illegible]	-
1	Aug 1949	360/22	30	[illegible]	-
ABLE	Aug 1950	14	19	15(E)	-
DOG	Sep 1950	[illegible]	[illegible]	[illegible]	-
ABLE	May 1951	16	-	[illegible]	-
HOW	Oct 1951	[illegible]	[illegible]	[illegible]	-
TS 1	Feb 1952	16	-	[illegible]	-
BARBARA	Aug 1953	030/55	[illegible]	[illegible]	-
FLORENCE	Sep 1953	-	-	[illegible]	-
CAROL	Aug 1954	[illegible]	[illegible]	[illegible]	-
EDNA	Sep 1954	[illegible]	[illegible]	[illegible]	-
HAZEL	Oct 1954	170/40	[illegible]	[illegible]	[illegible]
CONNIE	Aug 1955	030/55	79	[illegible]	[illegible]
DIANE	Aug 1955	160/36	[illegible]	[illegible]	-
IONE	Sep 1955	[illegible]	[illegible]	[illegible]	-
FLOSSY	Sep 1955	050/30	40	[illegible]	-
TS 1	Jun 1957	[illegible]	[illegible]	[illegible]	-
BECKY	16 Aug 1958	24	-	[illegible]	-
DAISY	28 Aug 1958	[illegible]	24	[illegible]	-
HELENE	Sep 1958	[illegible]	[illegible]	[illegible]	[illegible]
TS 3	Jun 1959	270/16	[illegible]	[illegible]	-
CINDY	Jul 1959	180/25	[illegible]	[illegible]	-
BRENDA	Jul 1960	[illegible]	[illegible]	[illegible]	-
DONNA	Sep 1960	100/46	[illegible]	[illegible]	-
ESTHER	Sep 1961	[illegible]	24	[illegible]	-
TS 6	Sep 1961	[illegible]	35	[illegible]	-
ALMA	Aug 1962	[illegible]	[illegible]	[illegible]	-
GINNY	Oct 1963	[illegible]	31	[illegible]	-
TS 1	Jun 1964	[illegible]	-	[illegible]	-
CLEO	1 Sep 1964	[illegible]	25	25(E)	-
DORA	13 Sep 1964	[illegible]	22	45(R)	-
ISBELL	Oct 1964	-	-	[illegible]	-
TS 1	Jun 1965	[illegible]	-	15(R)	-
ALMA	Jun 1966	[illegible]	[illegible]	50(R)	-
DORIA	Sep 1967	[illegible]	-	23(E)	-
ABBY	Jun 1968	14	-	[illegible]	-
DOLLY	Aug 1968	[illegible]	-	[illegible]	-
GLADYS	Oct 1968	[illegible]	[illegible]	[illegible]	-
ANNA	2 Aug 1969	[illegible]	-	[illegible]	-
CAMILLE	20 Aug 1969	[illegible]	-	[illegible]	-
GERDA	Sep 1969	[illegible]	-	[illegible]	-
KARA	Oct 1969	[illegible]	-	[illegible]	-
ALMA	May 1970	[illegible]		[illegible]	-
TS 4	Aug 1970	[illegible]	[illegible]	[illegible]	[illegible]
ARLENE	Jul 1971	[illegible]	-	[illegible]	-
BETH	13 Aug 1971	11		[illegible]	-
DORIA	27 Aug 1971	[illegible]	[illegible]	[illegible]	-
GINGER	Sep 1971	[illegible]	[illegible]	[illegible]	[illegible]
ST 1	May 1972	[illegible]	[illegible]	[illegible]	[illegible]
AGNES	Jun 1972	[illegible]	[illegible]	[illegible]	-
DAWN	Sep 1972	10		[illegible]	-
ST 2	Jul 1973	[illegible]	-	[illegible]	-
ST 1	Jun 1974		-	[illegible]	-
ST 11	Oct 1974	[illegible]	[illegible]	[illegible]	-
AMY	Jun 1975	-	-	[illegible]	
BLANCHE	Jul 1975	-	-	[illegible]	
HALLIE	Oct 1975	-	-	[illegible]	
ST 1	May 1976	-	-	[illegible]	[illegible]
BELLE	Aug 1976	-		[illegible]	
ST 8	Sep 1976	-	-		
BABE	8 Sep 1977	[illegible]	-	[illegible]	
CLARA	6 Sep 1977	[illegible]	[illegible]	[illegible]	
BOB	Jul 1979	[illegible]	-	[illegible]	
DAVID	Sep 1979	-	[illegible]	[illegible]	

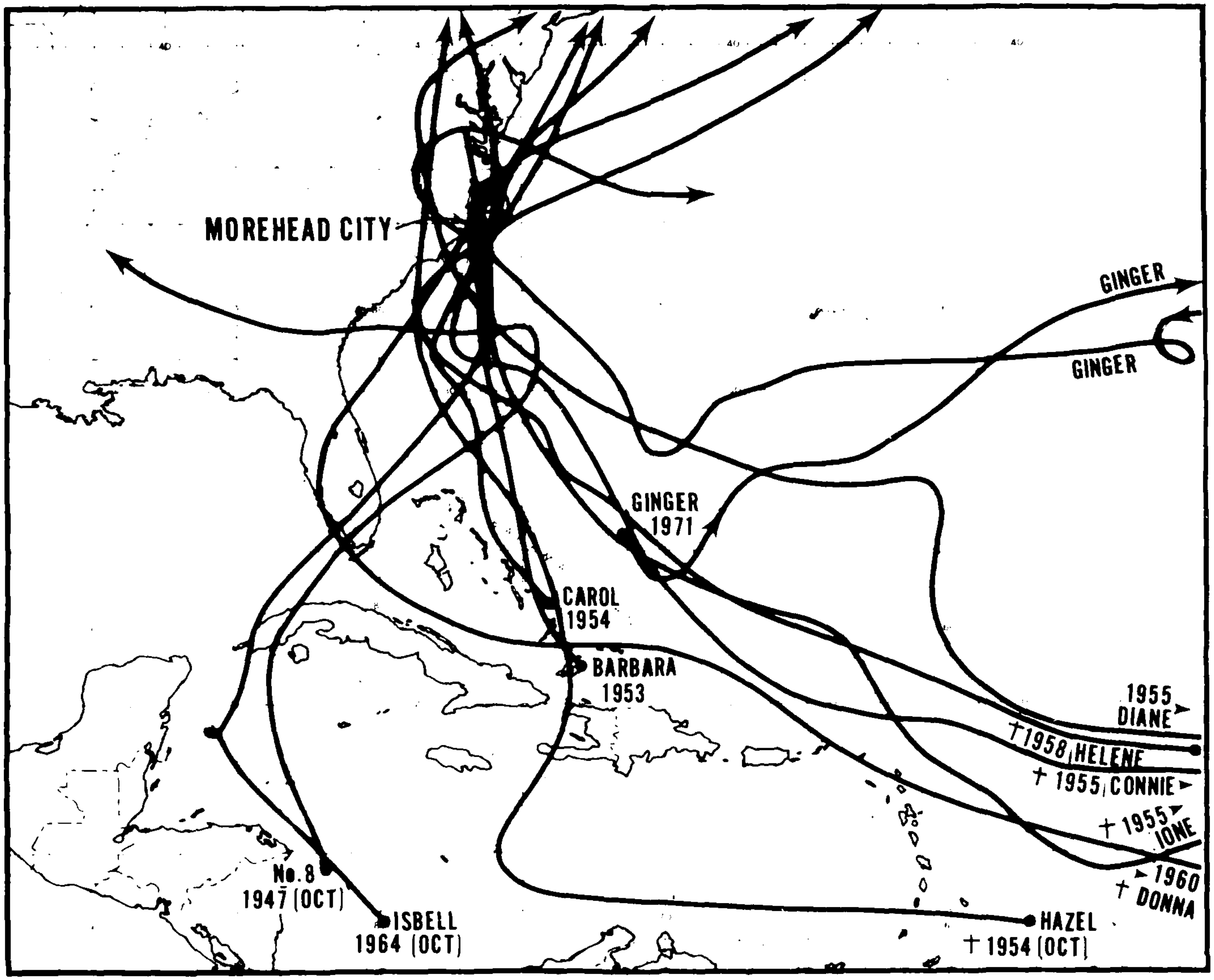


Figure VII-12. Tracks of the 11 hurricanes during the period 1945-1980 that produced winds of 34 kt or greater at MCAS Cherry Point. Included are 10 of the 12 storms during 1945-80 that produced winds at Morehead City estimated at 48 kt or greater, and all five storms (marked †) that produced measured winds at Morehead City of 64 kt or greater.

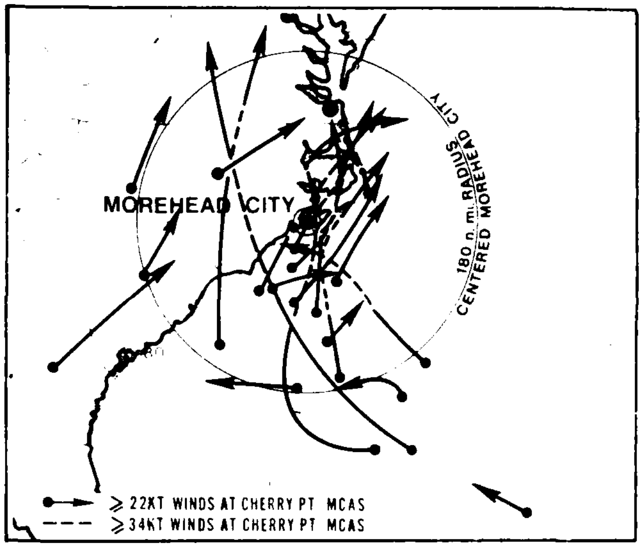


Figure VII-13. Track segments of the 21 tropical cyclones that produced winds of 22 kt or greater at MCAS Cherry Point, showing positions of storms' centers at beginning and ending of both 22 kt and 34 kt winds. Some bias is evident toward storms that are approaching along overwater tracks and have completed their process of recurvature onto northeasterly tracks.

speculative matter of wind direction during tropical cyclone passes near Morehead City has been attempted. For the majority of intense tropical cyclones approaching from the open ocean, one can visualize a period of strong southerly or southeasterly winds being followed by strong northerly or northeasterly winds.

The average frequency with which *hurricane force winds can be expected* at Morehead City, implied by both the estimated winds of Table VII-1 and earlier records for Carteret County from 1900 (National Weather Service, 1979), is once every 9 or 10 years. This compares with a frequency of once in 6 years for the same period at Cape Henry (see Figure VII-1) but only once in 30 years at Norfolk, Virginia and implies a high degree of exposure to destructive force winds at Morehead City.

3.2.3 Wave Action

The outer banks, consisting of Bogue Banks to the west of Beaufort Inlet and Shackleford Banks to the east (see Figures VII-2 and VII-3), defend most of the port facilities which lie to the north from the direct effects of deep ocean swell. Even under the combined action of open ocean swell and storm surge (see Section 3.2.4), widespread washover of the outer banks is rare. Some direct effect of ocean swell at the LST ramps or the southern tip of Radio Island can be envisaged by slight diffraction of southerly or southeasterly swells, such as would occur ahead of most storms advancing toward the port. High storm tides could also lead to penetration of southerly swells across Bird Shoal to the Front Street berthing facilities at Beaufort.

The generation of waves in the Sounds behind the outer banks is limited by either water depth or fetch. At the State Port Terminal, the worst exposure to wave action is at the south and east-facing berths (Berths I through VII, Figure VII-4) during strong southeasterly winds. For example 50 kt southeasterly winds could generate waves of up to 3 ft (U.S. Army Coastal Engineering Research Center, 1973). The west-facing berths (VIII and IX) are protected from wave action by the shoal grounds to the west and also, the climatological improbability of strong westerly winds during tropical cyclone passes at the port.

3.2.4 Storm Tides and Currents

The abnormally high coastal water levels associated with the passage of hurricanes or other severe storms are caused by the combined effects of low atmospheric pressure and strong winds at the ocean surface. This phenomenon, known as storm surge or storm tide, is defined as the difference between the observed water level and that which would have been expected in the absence of the storm. Its main component, when associated with an approaching hurricane, can be visaulized as a moving dome of water centered typically 20 or 30 miles to the right of the eye when viewed along the direction of movement of the storm. This dome of water is sometimes referred to as the "Hurricane Wave" or, more popularly but erroneously, the "Tidal Wave." There is additionally, a less dramatic increase in water levels detectable at Morehead City up to 12 hours before arrival of the storm, caused by the larger scale wind and pressure field. Local forecasting rules for Morehead City (NWS, Wilmington, NC, 1979) indicate that these large scale effects of the wind field are mainly associated with SE and NE winds. A 50 kt wind produces flooding on the city waterfront within 3 hours from onset if its timing corresponds with astronomical ("normal") high tide. The open ocean is clearly the source of floodwater during southeasterly winds whereas the waters of Pamlico Sound driving southwestward make a large contribution to local floods during northeasterly winds. Both strong southeasterly and northeasterly winds can be expected from the majority of tropical cyclones which pose a serious threat to Morehead City (see Section 3.2.1). These storms typically approach the port over water from the south, when gradual filling of the Sounds behind the outer banks occurs as the ocean level rises under the influence of southeasterly winds. A more dramatic inrush of water through Beaufort Inlet can be visualized at the arrival of the Hurricane or "Tidal" wave. At Hurricane Donna's approach in 1960, this inrush of water washed over the rail and road causeway between Radio Island and Beaufort carrying railway locomotives into the marsh to the north of the causeway. As Donna's eye passed to the north, winds at the port veered from an estimated maximum of 65 kt from the southeast to less than 30 kt from the north. Despite

the apparent decrease in its driving force, this reversal of the wind field and associated increase in atmospheric pressure caused the accumulated waters in the Sounds surrounding the port to drain seawards with destructive force. The outrush of water from Bogue Sound ripped a U.S. Army dredger from its moorings on the south-facing wharf of the State Port Terminal. Eyewitnesses recall a 1 inch diameter steel headrope parting as the east-going current carried the vessel's bow away from the wharf. With great presence of mind, her crew beached the vessel on the western shore of Radio Island by taking on more ballast. A small coaster (350 ft L.O.A.) which elected to remain moored to the Aviation Fuel Terminal saw fit to lay two anchors out into the main ship channel to supplement lines securing her to the mooring dolphins. This vessel remained at her berth without incident despite the strong southeast-going drainage current through the main ship channel, which carried 13 of the 16 channel markers off station.

This account of Donna's storm tide effects emphasizes the special significance of the confluence of drainage from the sounds at Morehead City to ships at the port during a tropical cyclone pass. The forces which would be exerted on large, ocean-going vessels by such currents would make the south and east-facing berths (I through VII) at the State Port Terminal and Aviation Fuel Terminal untenable. Berths VIII and IX lie outside the main drainage fairway of Bogue Sound but by the same token, would probably shoal badly as a result of the massive sediment transport through the adjoining channel. Such rapid currents would also preclude anchoring for vessels in the deep channels of the sounds during a tropical cyclone pass.

The earliest recollections of similarly destructive currents at the port relate to Hurricane Hazel in 1954. Table VII-2 presents details of all hurricanes which have produced significant flooding at Morehead City (i.e., tides of more than 3 ft above MSL) since Hurricane Hazel. It is evident that Hazel and Donna do not distinguish themselves in regard to high water levels at the port, but rather in the difference they caused between the water [illegible] the Outer Banks and at the port itself. It is this gradient wh[illegible] currents and is inclined to be more pronounced the faster the [illegible] approaches. Table VII-2 shows both Hazel and Donna to be [illegible] high speeds of advance. They are both hurricanes which had [illegible] completing the process of recurvature well south of Morehead [illegible] they subsequently made a landfall to the west of the port [illegible] the full effects of the "Hurricane Wave" at Beaufort Inlet.

It is very unlikely that vessels would be damaged at the [illegible] Terminal by exceptionally high water levels alone because the [illegible] to 10 ft above MSL. However, such very high water levels [illegible] associated with either destructively rapid currents or high wi[illegible]

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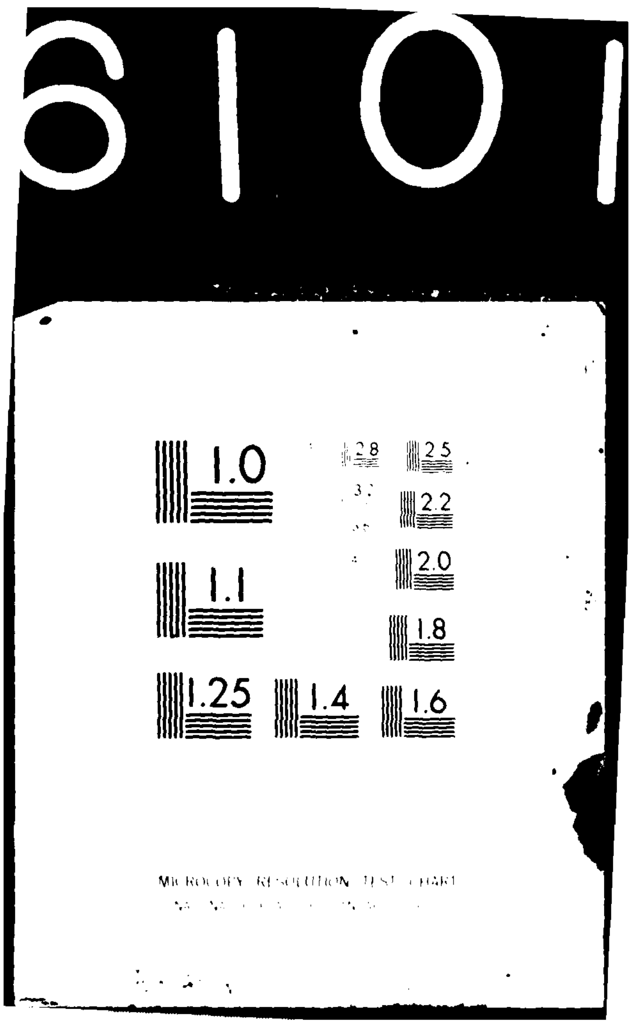
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Table VII-2. High water levels associated with hurricanes producing significant flooding at Morehead City from 1954 to 1980. Note the large difference in water levels between the Outer Banks and the port caused by the two rapidly advancing storms: Hazel and Donna.

Hurricane		High Water Level (ft above MSL)			Speed of Advance (kt)	Passing Side
Name	Date	Morehead City	Beaufort	Outer Banks		
HAZEL	Sep 1954	6.0	8.8	11 (est)	30	W
CONNIE	12 Aug 1955	4.3	-	5.0	6	E
DIANE	17 Aug 1955	4.3	5.1	5.1	10	W
IONE	Sep 1955	6.0	6.6	7.2	11	W
HELENE	Sep 1958	3 to 5	-	-	17	E
DONNA	Sep 1960	5.2	7.5	10.6	27	W
GINGER	Sep 1971	2 to 4	-	-	5	W

high water level associated with Hurricane Hazel (Table VII-2) is considered to represent a once in 100 years event (Ho and Tracey, 1975). These authors predict water levels at the Outer Banks of 14.2 ft once in 500 years - given by the near pass of a hurricane of similar intensity to Camille, which devastated the Mississippi coast in 1969.

The foregoing references to water levels all include the effects of astronomical tides which have a mean range of 2.8 ft at Morehead City. In fact, Hurricane Helene in 1958 (see Table VII-2) passed just offshore during astronomical low tide at the port, which moderated the effects of this intense, accelerating storm. Normal tidal currents of up to 3 kt occur in the harbor and place certain restrictions on pilotage (see Section 4.1). As noted above, these currents can be dramatically affected by the passage of tropical cyclones.

In summary, the greatest threat to ships at the State Port Terminal from storm tides and their associated currents is presented by hurricanes which advance rapidly after having completed their process of recurvature south of Morehead City and which subsequently make a landfall to the west of the port.

4. THE DECISION TO EVADE OR REMAIN IN PORT

The foregoing tropical cyclone climatology for Morehead City indicates that its site on a marshy promontory which lies across the path of the majority of recurving or recurved tropical storms in the main North Atlantic basin, leads to a high frequency of destructive force winds at the port. A low island barrier absorbs the impact of deep ocean swell, but the port offers little protection from winds which, under particular circumstances of the tropical cyclone threat, may be accompanied by very high tides and tidal currents of exceptional force at the port terminal itself. The absence of sheltered berths or anchorages

makes evasion at sea the safest course of action for seaworthy deep-draft vessels as soon as it can be established that a particular tropical cyclone poses a threat of destructive winds or tides at Morehead City.

Both Navy and Coast Guard authorities formalize their assessment and expression of the tropical cyclone threat, as it is perceived from real-time forecasts and warnings, by setting and promulgating Tropical Storm/Hurricane Conditions of Readiness. Instructions to Navy units are contained in COMNAVBASENORVA INST 5400.1D as amplified by NAVPHIBASELCREEKINST 3141.2C and held by OIC, Naval Port Control Office, Morehead City who is SOPA (ADMIN). Commercial vessels should liaise with Coast Guard and Port Management authorities.

The following specific pointers from the Morehead City tropical cyclone climatology will form a useful supplement to real-time forecast information in assessing a particular threat and setting Tropical Storm/Hurricane Conditions:

(1) The principal threat of destructive force winds and exceptionally high tides is posed by tropical cyclones originating in the tropical waters of the main North Atlantic basin in August and September which recurve northwards so that the last 300 miles or more of their approach towards the port lies over water and which subsequently strike or pass close to the port.

(2) These storms pose an additional threat of destructive tidal currents if they accelerate to speeds of advance of 20 kt and more, after completing recurvature over water to the south of the port, and subsequently make a landfall within 100 n mi to the west of the port.

(3) A lesser threat of destructive force winds exists from tropical cyclones originating in the Caribbean or Gulf of Mexico in September or October, which subsequently enter the main basin of the North Atlantic at a sufficient range to permit at least 300 n mi of their final approach to the port to be made over water.

(4) It is unlikely that any tropical depression forming within 300 n mi of the port will threaten destructive force winds at the port.

4.1 EVASION AT SEA

Timing of the sortie depends upon the vessel's speed capability in relation to the forecast speed and track of the storm, allowing a suitable margin for delays in obtaining the services of tugs and pilot and for establishing ample sea room to be able to accommodate changes in the storm's behavior. Execution of sortie must be made sufficiently far in advance of deteriorating weather conditions both over the planned evasion route as well as at the port, so that the vessel's ability to evade at sea is not hampered by high sea states. This last consideration is especially important to LSTs. On the other hand, vessels with a large sail area, e.g., Navy LPHs or larger amphibious assault vessels

or larger commercial tankers and similar bulk carriers, will pay more heed to the tidal and wind limitations on pilotage at the port. LPHs should maneuver for sortie at slack water if possible and, depending upon available tug power, clear the port before increasing winds hamper harbor operations and cause further delay.

Wind limits governing the sortie decision must be interpreted in relation to the uncertainties of the forecast track and intensity of the threat storm. A hurricane with maximum winds of 120 kt at a radius of 30 n mi forecast to pass within 100 n mi of the port giving a possible 50 kt wind locally, is a greater threat than a 60 kt storm forecast to make a direct strike on Morehead City. Bearing in mind these limitations, the recommended limits are as follows:

(1) Vessels with a large sail area, including LPHs and LHAs and the larger commercial tankers or bulk carriers, should plan to sortie if winds of 48 kt or above are expected.

(2) Smaller deep draft vessels and LSTs should plan to sortie if winds of 64 kt or above are expected.

Evasion route options are threefold: (See Figure VII-1)

(1) East-southeastwards (after clearing Cape Lookout Shoals) to the open ocean beyond the influence of the "Dangerous Semicircle" winds. Climatological records of storm tracks imply a minimum safe offing of 250 n mi. Real time forecast information will provide the best estimate of safe range from the storm's track.

(2) Coastwise northwards (taking care to clear offshore shoals) ahead of the storm with an option to seek shelter at the hurricane anchorages in Chesapeake Bay.

(3) Coastwise southwestwards (after clearing Frying Pan Shoals off Cape Fear) between the influence of "Safe Semicircle" winds and the shore.

The first is the most generally applicable option. It is appropriate to both major tropical cyclone threats at the port, i.e., storms approaching from the south and southwest. However, it demands a long seaward passage against increasing head winds and seas. Therefore, its safe execution is only possible after a sufficiently early departure to "cross the T" of the storm's track before the ship's speed is significantly reduced by deteriorating weather. It is the safest evasion route from storms approaching from the southwest and which are likely to be advancing at 25 kt or more. The latest recommended times to execute sortie by this route are 36 hours before the forecast onset of destructive force winds (i.e., soon after setting Hurricane Condition III) for LSTs and other vessels with similar speed limitations; or 24 hours (i.e., on setting Hurricane Condition II) for vessels capable of a 20 kt transit in moderate seas.

The second option may be chosen by Navy units for operational or logistical reasons, e.g., LSTs may opt to seek shelter at the hurricane anchorages in Chesapeake Bay[1] - a passage of 260 n mi from Morehead City. There is the risk of being overtaken by accelerating storms - increasingly likely at higher latitudes - and secondly the possibility that if a more northerly haven is reached, it could be affected later by the same storm before the vessel can be safely secured at its new berth against the effects of destructive weather. LSTs contemplating this option should sortie 48 hours before the forecast onset of destructive force winds at Morehead City (i.e., at the setting of Hurricane Condition III).

The last option is specifically recommended when the threat storm is approaching from the southeast and under no other circumstances. Winds and seas along this evasion route should be from astern permitting a relatively late departure. The storm's forecast track should be examined on setting Hurricane Condition III (48 hours before onset of destructive force winds). If the forecast track lies clear to the east of the meridian through Morehead City to the south of the port, then sortie along the southwesterly route can be safely executed up to 24 hours before the onset of destructive force winds. If the storm's forecast track crosses this meridian to the west more than 60 n mi south of the port, evasion plans should be revised. Immediate sortie to the southwest may still be possible or the safer option of immediate sortie to the east-southeast (First Route Option above) may be taken instead.

4.2 RETURNING TO HARBOR

The aftermath of a tropical cyclone strike near this port is likely to include displaced navigational markers and severe shoaling of dredged channels. A check with the harbor authorities is recommended before attempting to return.

4.3 REMAINING IN ALONGSIDE BERTHS

Disabled deep draft vessels or vessels unable to evade at sea for other reasons, should make preparations at the first indications of a hurricane threat, especially if assistance with re-berthing is required as tug services, will later be under heavy demand by sortieing vessels.

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[1] See Section II of the Hurricane Havens Handbook: "An Evaluation of Norfolk, Virginia as a Hurricane Haven."

The following recommendations are offered to masters of vessels securing against a hurricane threat:

(1) Read the account in Section 3.2.4 of this report on Hurricane Donna's impact in 1960.

(2) Berth IX and to a lesser extent Berth VIII offer some protection to deep draft vessels at the State Port Terminal. Be wary of the hazard in destructive force winds from loose merchandise in the staging areas next to these berths (Kraft, 1980).

(3) Use all securing means available including anchors, especially if forced to occupy more exposed berths in the harbor.

(4) Merchantmen should contemplate ballasting down against the effects of exceptional currents and winds.

(5) LSTs forced to remain at *Morehead City* should contemplate beaching by running kedges out over the shoal ground in Bogue Sound making use of the hard sand to the south of the Intracoastal Waterway opposite Sugar Loaf Island (see Chart 11547, Morehead City Harbor).

5. ADVICE TO SHALLOW DRAFT VESSELS

The Morehead City/Beaufort port area is badly exposed to the destructive effects of both winds and storm surge associated with hurricanes approaching from the open ocean. Small recreational craft should, if possible, be removed from the water and firmly secured in a sheltered location ashore when a "Hurricane Watch" is issued.

Bearing in mind that bridges will remain closed to waterborne traffic during a hurricane threat, larger vessels should secure in those creeks and waterways further inland which offer the shelter of surrounding woodland. The following comparison illustrates the principles involved:

Peletier and Spooners Creeks (see Chart 11543, Morehead City Harbor) off the Intracoastal Waterway in Bogue Sound are bounded by good piling and offer some protection from destructive winds by the nearby woodland. Damage is more likely this close to the open ocean, from storm surge which may be associated with seas over-topping Bogue Banks in the case of a near strike by a hurricane. Furthermore, recent developments along Bogue Banks present the strong possibility of approaches to these Creeks via the Intracoastal Waterway, being blocked with debris from mobile home parks and other structures on the dunes, for a considerable period after a hurricane strike. For these reasons, many craft, including fishing vessels, prefer to secure to trees along the Adams Creek Canal section of the Intracoastal Waterway just south of the Core Creek swing bridge (see Chart 11545, Beaufort Inlet and part of Core Sound). This is

roughly equidistant from Neuse River to the north and Beaufort Inlet to the south and therefore provides the best protection available within easy reach of the ports, from wind and tidal surge effects irrespective of their source direction.

Advice on the method of securing small craft to trees in sheltered creeks and waterways is found in the Coast Pilot 4 (1979), Cape Henry to Key West as follows:

> Hurricane moorings - small boats should seek shelter in a small winding stream whose banks are lined with trees - preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches, having more give, will ease shocks in gusts. Keep clear of tall pines as they have shallow roots and are more apt to be blown down.

The preference for cedar and mangrove for this purpose refers more particularly to Florida as does the warning against "tall pines with shallow roots." This warning is aimed at an Australian species of pine introduced into Florida at the beginning of the century and fortunately does not apply to the native pines of the Croatan forest of North Carolina.

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VIII: CONTENTS

VIII. NEW LONDON, CONNECTICUT

SUMMARY

The conclusions reached by this study are that during hurricane conditions (forecast winds 64 kt or greater), the main New London harbor is not a haven for most vessels and that the inner harbor is a haven for most vessels. The surrounding topography provides some protection from northeast through southeast winds for the eastern shore of the main and inner harbor, however the lower western shore of the main harbor is very exposed to southeast through south winds. The entire harbor (main and inner) is subject to the possibility of major storm surge flooding and the main harbor could possibly experience a tidal bore in the case of a severe storm making landfall in Connecticut west of New London.

It is the recommendation of this study that those U.S. Navy vessels able to get underway and not able to use the NAVSUBASE piers evade at sea when a tropical cyclone exceeding or forecast to exceed hurricane force threatens New London. The main harbor must be considered a haven for the USS FULTON and vessels unable to sortie and not able to move to the NAVSUBASE. Nested submarines at the FULTON should shift berths to the NAVSUBASE or sortie. Channel depths upriver from Electric Boat as well as NAVSUBASE pier availability restrict the inner harbor's use by all vessels as a hurricane haven. In particular, the 726 class submarine has only one berth at New London (NUSC Pier 7) other than the facilities at Electric Boat.

Historically, the most dangerous tropical cyclones threatening New London have been extremely fast moving hurricanes. It is conceivable that such a threat can leave less than 24 hours to accomplish all destructive weather preparations (sortie, shift berths, etc.).

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

New London Harbor is on the northern shore of Long Island Sound at the mouth of the Thames River as illustrated in Figure VIII-1. The main harbor comprises the lower 3 miles of the river from Long Island Sound to the vicinity of the bascule railroad and twin highway bridges, connecting Groton and New London, and includes Shaw Cove, Winthrop Cove and Greens Harbor. The inner harbor extends about 9 miles upriver from the highway bridges. Figure VIII-2 shows the area of the lower Thames River including the ports of New London, . oton, and the Naval Submarine Base. Significant naval and port facilities are depicted.

This hurricane haven evaluation was prepared by J.D. Jarrell and A.B. Lund of Science Applications, Inc. (SAI), Monterey, CA 93940.

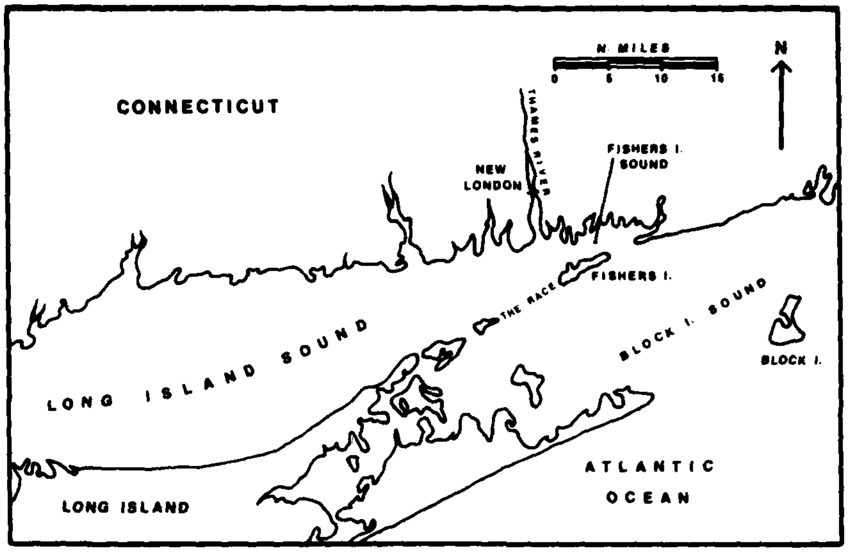

Figure VIII-1. Approaches to New London.

The main harbor is open to the south. Hills or bluffs extending to about 100 ft line the harbor both east and west, except for some fairly flat topography on the lower third of the harbor's eastern shore (exposing the harbor to southeast winds). Along the river above the highway bridges the topography becomes slightly rougher with bluffs reaching to 200+ ft. Thus the river becomes a well defined channel for north/south winds.

Fishers Island and the eastern end of Long Island provide an effective barrier to deep ocean swell for the entrance to New London Harbor. Fetch limits and bottom topography of Long Island and Fishers Island Sound limit maximum wave heights within Long Island Sound.

2. THE HARBOR AND ITS FACILITIES

2.1 NAVAL UNDERWATER SYSTEMS CENTER (NUSC) NEW LONDON LABORATORY AND COAST GUARD STATION

NUSC berthing facilities consist of two piers (Piers 4 and 7) and the Coast Guard Station mooring facilities. Water depth alongside the northernmost pier, pier 7, is 42 ft below mean low water (MLW) on the north side and less on the south. Pier 4 depths alongside are 19-20 ft below MLW. Pier 4 is a 555 ft wooden pier. Pier 7 is a 656 ft concrete pier capable of handling one Ohio Class submarine on the north side only. Deck heights are approximately 8 ft above MLW for pier 4 and 15 ft for pier 7. Pier 4 is outboard of pier 7 and is exposed to incoming seas, thus sheltering pier 7 somewhat. The Coast Guard mooring facilities nearby have quite low deck heights and are not suitable for hurricane berthing.

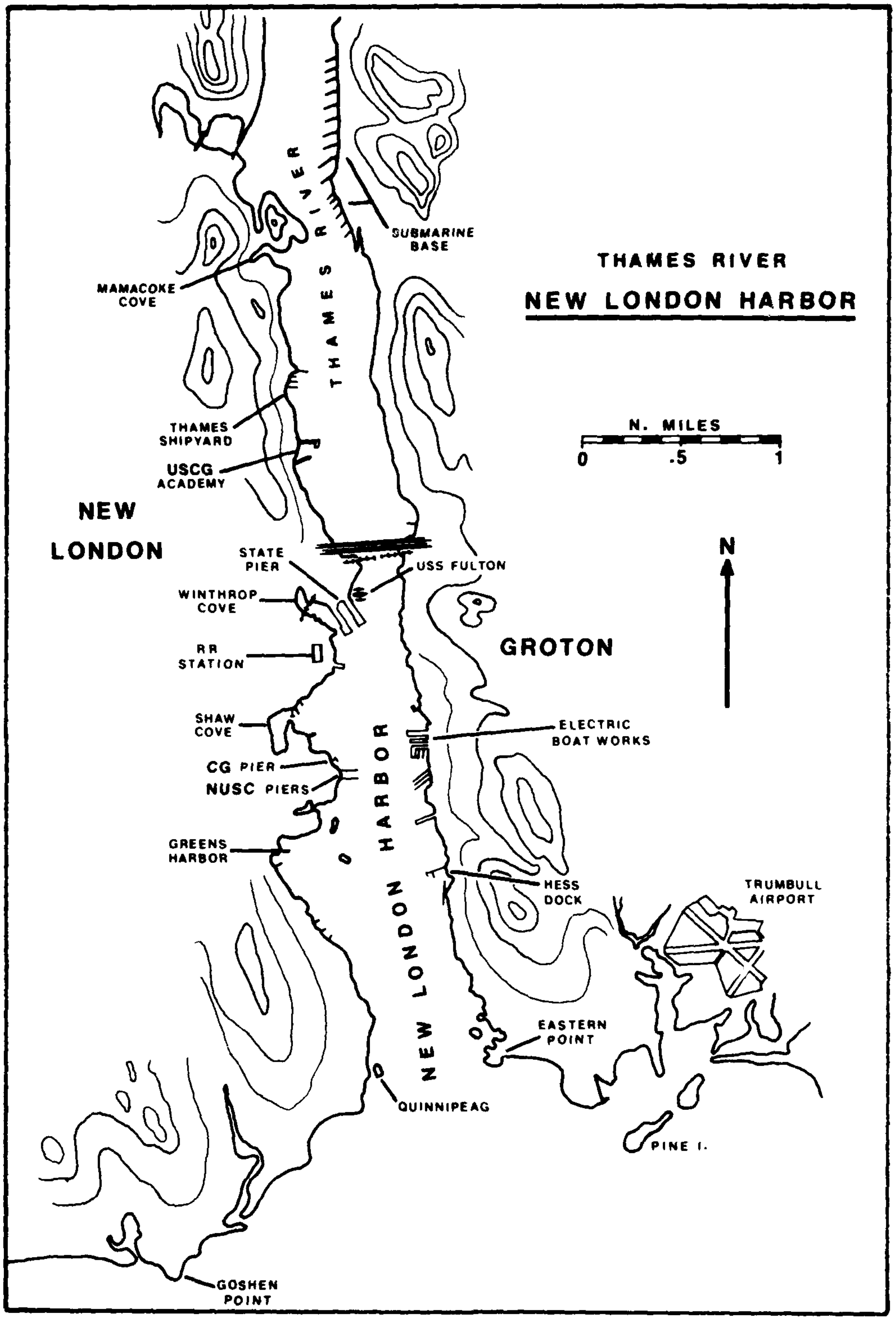

Figure VIII-2. New London Harbor and major port facilities.

2.2 STATE PIER

State Pier, Port of New London, owned by the State of Connecticut is located at the head of the harbor just below the railroad bridge. The Navy leases and controls all space except the west side which is used for commercial dry cargo vessels. State Pier is the home port for Submarine Squadron TEN (SSN Class submarines). The submarine tender, USS FULTON, is semi-permanently Mediterranean moored at 4 concrete dolphins on the northeast side of State Pier. FULTON, together with its nest of submarines, is depicted in Figure VIII-3. The land and bridge abutments north of the FULTON's berth provide the ship with some shelter from north winds. The depth alongside State Pier is 39 ft below MLW on the east, 30 ft on the face and 29-33 ft on the west. The deck height is 10 ft above MLW. Vessels at the pier normally back underway into center channel and then proceed forward.

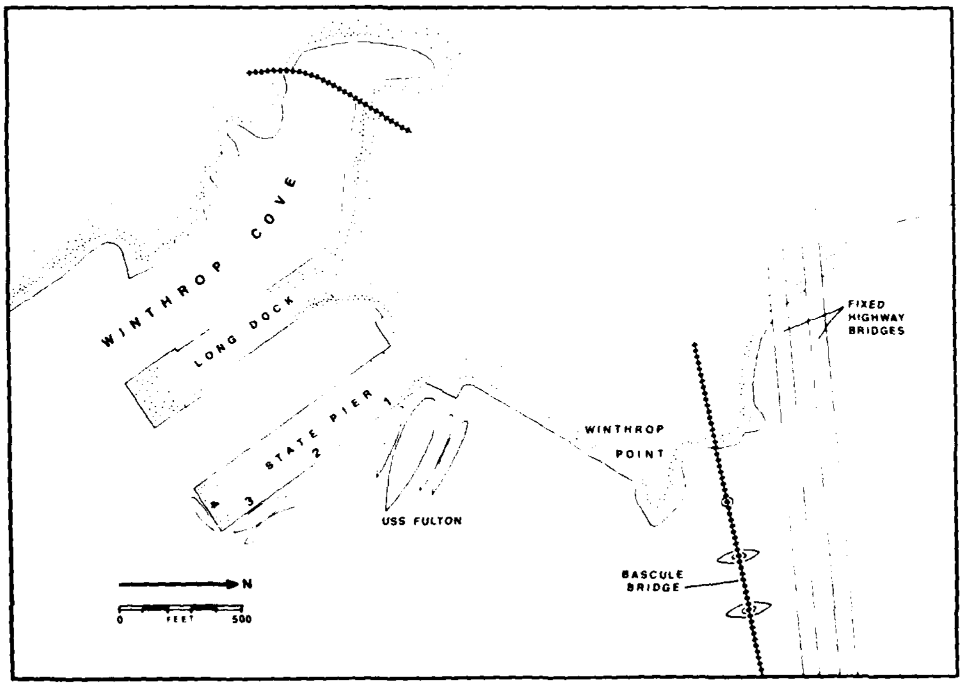

Figure VIII-3. State pier facilities.

2.3 NAVAL SUBMARINE BASE (NAVSUBASE)

Located about 1 1/2 miles above the railroad bridge which separates the main and inner harbors, the NAVSUBASE waterfront, illustrated in Figure VIII-4, consists of several piers of a variety of wood and concrete construction. Pier improvement and construction is ongoing according to a master plan which will expand and upgrade the facilities for SSN, 688 Class SSN and SSBN submarines of Submarine Squadrons Two, Ten and Twelve. In early 1981 there existed a maximum of 8 concrete piers (2, 6, 10, 12, 13, 15, 31, 32) with a maximum capacity of 14 ship berths. Future expansion includes more concrete piers, as well as some nesting capabilities at two piers and a weapons pier capable of handling up to 688 Class SSN's. Figure VIII-4 also illustrates topography which provides considerable shelter from the easterly components of winds. Also shown is the portion of the lower base susceptible to inundation by an 11.2 ft, 100-year flood level.[1]

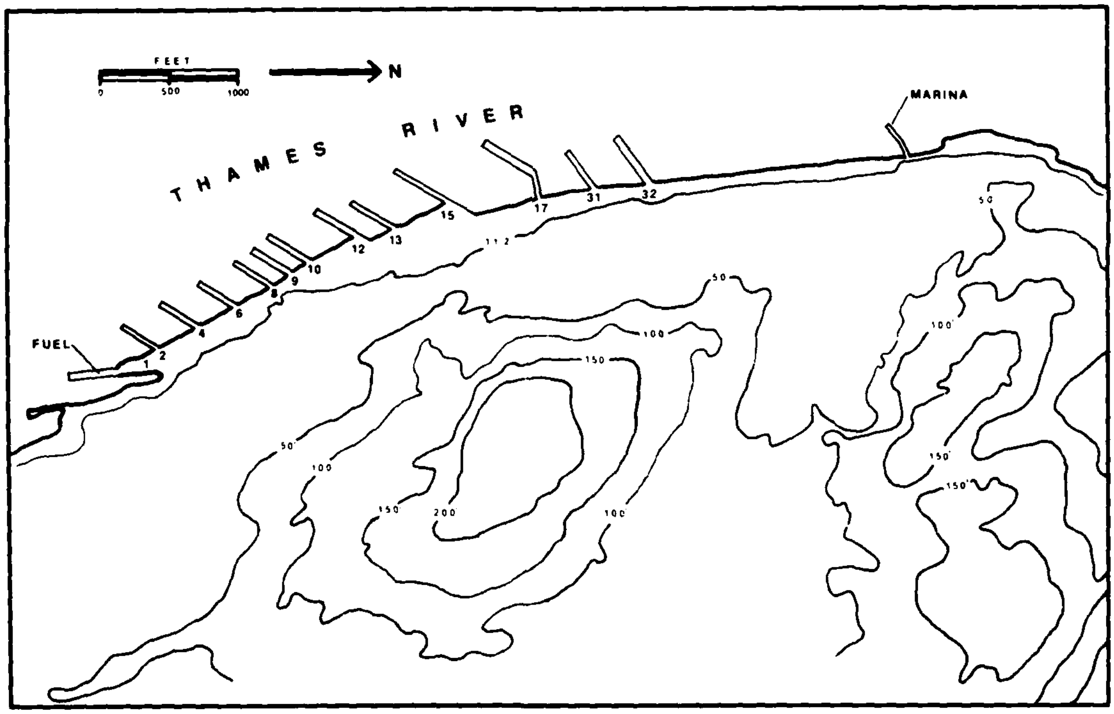

Figure VIII-4. Naval Submarine Base, New London. The 11.2 ft contour represents a 100-year flood level which includes most of the lower base facilities.

[1] 100-year flood level (flood tide) - a tide generated by a hurricane which is equaled or exceeded once in 100 years (1% chance of happening in any one year).

2.4 COAST GUARD ACADEMY PIER

This pier is used by the Academy's sailing ship EAGLE, a Coast Guard Cutter and other miscellaneous small craft. Depths alongside the 450-ft pier range from 16 ft below MLW on the face, 15 to 20 along the south side and 12 to 17 ft on the north side. The pier is exposed to northerly winds.

2.5 ELECTRIC BOAT SHIPYARD

The Electric Boat Division of General Dynamics Corporation has a variety of docks which have a very low deck height (6 ft above MLW). Since this facility is reserved for ship building/repair, submarines in various states of repair may be found here, including unmanned new construction vessels. A variety of barges will also be found here, including barges with ship's companies living aboard.

2.6 HESS OIL AND CHEMICAL DOCK

Hess Dock is a privately owned sturdy structure on the east side of the river opposite Greens Harbor. This facility now has a 600-ft dock dredged to 42 ft below MLW for a total length of 1050 ft. The deck height is 8 ft above MLW.

2.7 NEW LONDON HARBOR MISCELLANEOUS FACILITIES

New London Harbor has more than 30 wharves and piers, used as repair berths and for mooring recreational craft, fishing vessels, tugs, barges, ferries and government vessels. Many of these facilities are located between Shaw Cove and State Pier. Depths alongside these facilities range from 10 to 30 ft.

Greens Harbor is a small craft shelter just north of the New London harbor entrance, it is exposed to southeast winds. Shaw Cove is a dredged basin for small craft located between NUSC and the downtown New London wharves. There is a railroad bridge with a swing span over the entrance. Winthrop Cove is at the northern edge of the downtown New London wharf area, and includes some ferry facilities.

2.8 CHANNELS

The channel was recently dredged to a depth of 40+ ft below MLW from the channel entrance to the north end of Electric Boat, including a turning basin up to pier 7 at NUSC, providing access for the deep draft Ohio (726) class submarines. From Electric Boat upriver, the channel depth is 36 ft to just beyond NAVSUBASE pier 32. These shallower depths preclude 726 class access to the NAVSUBASE or to State Pier and the USS FULTON.

2.9 REFERENCES AND CHARTS

The reader is referred to the following publications for details of the harbor and its facilities:

DMA Hydrographic/Topographic Center, 1979, Publication 940, Chapter 2, Fleet Guide New London.

U.S. Department of Commerce, 1979, Chart 13212, Thames River-New London Harbor-Long Island Sound to Norwich.

U.S. Department of Commerce, 1980, Chart 13213, New London Harbor and Vicinity.

U.S. Department of Commerce, 1979, United States Coast Pilot 2, Atlantic Coast, Cape Code to Sandy Hook.

3. HEAVY WEATHER FACILITIES AND HURRICANE ANCHORAGES

3.1 TUG AVAILABILITY

The availability of tugs is adequate considering that the commercial vessel usage of the port is minimal. A total of 10 to 12 tugs are available in New London Harbor from various sources including the NAVSUBASE, Electric Boat, Thames Drydock Company and Whaling City Dock and Dredge.

3.2 HURRICANE BERTHING

The more substantial concrete piers at the NAVSUBASE are considered to provide suitable berthing for up to 14 vessels in the event of a hurricane threat despite their susceptibility to inundation (see Section 5.3.2). With suitable preparations the dolphins at State Pier can serve as a hurricane berth for the USS FULTON (see Section 5.3.1). The absence of suitable hurricane berthing for the deep draft 726 class presents a serious problem. Vessels under construction or repair at the Electric Boat shipyard can probably be safeguarded adequately. In an emergency or in marginal threat conditions, the north side of NUSC pier 7 could serve as a hurricane berth for one 726 class submarine, keeping in mind the exposure of this location to wind, floating debris and moderate wave action. The remaining facilities in the main harbor area do not offer adequate protection during a hurricane threat.

3.3 HURRICANE ANCHORAGES

Shallow draft anchorages A, B and C[2] provide good holding ground, but B and C are very exposed and are not recommended as hurricane anchorages. Anchorage A is more protected from northeasterly and easterly winds but it is too shallow and would not have been tenable during the 1938 hurricane[3], since most major harbor damage occurred nearby. It may be suitable for lesser threats. It is proposed that a new designated shallow draft anchorage immediately above the bridges in the river be investigated. This anchorage area would be much less exposed to southerly wind components with the protection afforded by the bridges and abutments. The constriction of the river at the bridges and the widening of the river above the bridges would limit storm surge energy passing through, effectively preventing any wall of water (tidal bore) north of the bridge. Also this anchorage would be much less exposed to debris.

Deep draft anchorage opportunities, although exposed to the wind, are available in Long Island Sound. Short fetch and shallow waters at the eastern end of Long Island Sound limit wave growth from that direction. The Long Island land mass and the Connecticut mainland limit north/south fetch. Although the sound extends quite a distance west, the fetch and bottom depths limit wave growth from the lesser westerly hurricane winds. The Race area between Fishers and Long Island drastically reduces the height of deep ocean waves which enter Long Island Sound.

3.4 HURRICANE PLANS AND PREPARATION

The Port of New London does not have an overall hurricane preparation plan since there are few threats and few commercial vessels using the port. The Commanding Officer of the Coast Guard Station, as Captain of the Port, is responsible for the safety of vessels and waterfront facilities except for Navy vessels and facilities. He receives his official hurricane warnings from the Group Commander in New Haven. Commander Submarine Group TWO (COMSUBGRU TWO) is the Navy's Immediate Area Coordinator (IAC) for New London, receiving hurricane warnings via Navy message channels and setting local area storm conditions for all Navy units. COMSUBGRU TWO/IAC NLON OPORD 2000 Appendix 5 to Annex C, provides heavy weather guidance for sea-going units at New London.

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[2] Fleet Guide New London.

[3] The hurricane of September 21, 1938 caused disastrous property damage and loss of life in New England. The most intense storm to occur in the New London area in at least the last century, hit with hurricane force winds and a large storm surge. Little or no warning was provided because of the storm's high rate of forward motion.

4. TROPICAL CYCLONES AFFECTING NEW LONDON

4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone approaching within 180 n mi of New London is considered a threat. It is recognized that a few tropical cyclones that did not approach within 180 n mi may have affected New London in some way, so to some extent this criterion is arbitrary. Information on Atlantic tropical cyclones that passed near New London is available as far back as 1871. Data for the period 1871-1979 (109 years) was used to generate strike probabilities, time to closest point of approach (CPA), and direction of approach information presented in Figures VIII-8 through VIII-11. A shorter period, 1886 to 1979 (94 years), was used to construct the seasonal information presented in Figure VIII-5, since storm center wind information was not available for the cyclones occurring from 1871 to 1885.

Although tropical cyclones have occurred in the North Atlantic during all months of the year, all tropical cyclones which have threatened New London occurred from June through November. Figure VIII-5 depicts the monthly summary of tropical cyclone threat occurrences for the New London area. Of the 80 tropical cyclones which threatened New London in this 94-year period, 69 (86%) occurred in the months of August through October with the peak threat in August and September. The occurrence of tropical cyclones of hurricane intensity (winds $\geq$64 kt when within 180 n mi of New London) has a marked peak during August and September with 28 out of 33 or 85% occurring during those months (1886-1979).

Figure VIII-6 displays the storms as a function of the compass octant from which they approached New London. It is evident from this figure that the major threat from tropical cyclones is from the south and southwest.

An average of 0.8 tropical cyclones per year (or 4 in 5 years) pass within 180 n mi of New London. An average of 0.35 hurricanes per year (or 1 every 3 years) pass within 180 n mi of New London. The natural protection offered by the shape of the eastern coast of the United States south of New London to Cape Hatteras essentially dictates that most recurving storms must either make a landfall first south of Hatteras or pass New England well offshore to the southeast. The majority are lesser threats coming from storms which pass over water well to the southeast of New London, tending to follow the path of the oceanic Gulf Stream. However, occasionally storms are accelerated on a more northerly track instead of typically recurving to the northeast. An example would be the disastrous 1938 hurricane which advanced rapidly up the east coast offshore, passing Hatteras, moving over central Long Island, then over New Haven,

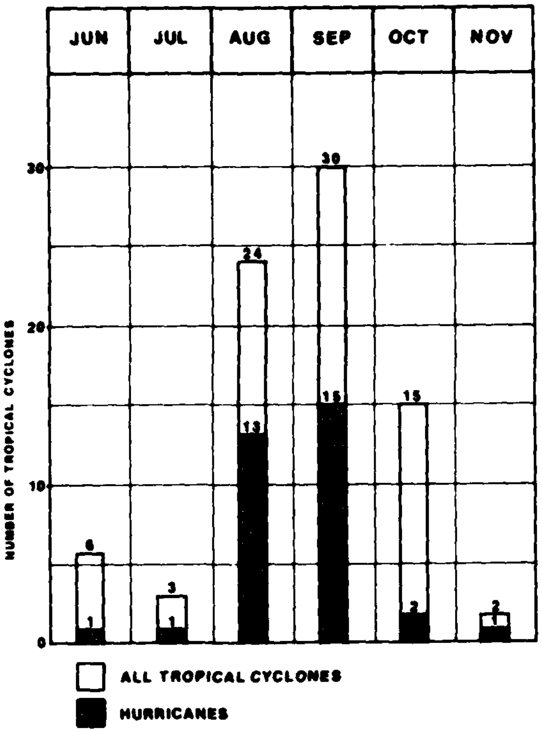
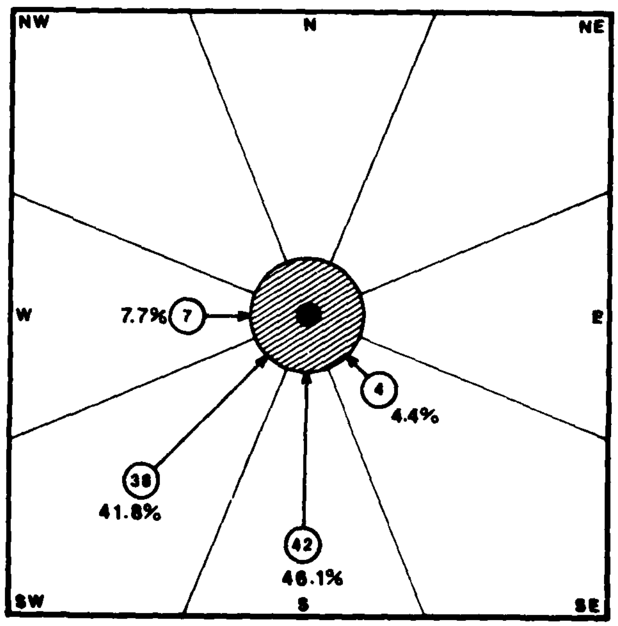


Figure VIII-5. Seasonal distribution of tropical cyclones passing within 180 n mi of New London, June-November (based on data from 1886-1979). Monthly totals are shown above each column; numbers of storms threatening with hurricane intensity are indicated by the hatched areas.

Figure VIII-6. Directions of approach of tropical cyclones toward New London during June-November (based on data from 1871-1979), and passing within 180 n mi of the port. Numerals in circles show the number of tropical cyclones approaching from each octant; the percent figure is the percentage of the total sample that approached from that octant.



Connecticut and then north-northwest into Vermont. Thus, instead of passing New England offshore, the hurricane accelerated until it was moving at an average rate of advance of 60 mph, leaving Hatteras at about 8:30 AM on 21 September and reaching Connecticut at about 4:00 PM on the same day. Such a rate of advance would be difficult to handle for storm preparations even with today's more sophisticated warning methods. Figure VIII-7 illustrates the very rapid approach of four such exceptional hurricanes which caused destruction at New London. With today's advances in meteorology, it is possible to identify those circumstances which lead to the rapid acceleration of tropical cyclones towards the north, although rarely would a 60 mph SOA be forecast. Figure VIII-7 shows that a hurricane can be offshore between Jacksonville and Cape Hatteras before its track begins to indicate it is heading for southern New England. This point, where the departure from a normal recurvature track takes place, can be as little as 24 hours from New London.

Figures VIII-8 through VIII-11 are a statistical summary of threat probability based on tropical cyclone tracks for the years 1871-1979[4]. The data base is presented seasonally with solid lines representing "percent threat" for the 180 n mi circle surrounding New London. The heavy solid lines represent approximate approach times to New London. For example, in Figure VIII-10, a tropical cyclone located near 30N, 75W in August has about a 40 percent chance of passing within 180 n mi of New London and if the speed remains close to the climatological normal, it will reach New London in about 2 to 3 days.

Annually (Figure VIII-8), the primary threat axis for New London is along the East Coast through Hatteras with the axis splitting near South Carolina, with higher probabilities from the Bahamas and lesser probabilities from the Gulf of Mexico. Most threat storms pass to the southeast of New London just off Cape Cod.

For late and early season storms, October through June (Figure VIII-9), the major threat axis is overland passing through central Virginia from the Gulf of Mexico. The source region for most of these threat storms is the western Caribbean and the Gulf of Mexico. Since 1889, only one off-season October-June storm (November 1899), has approached within 180 n mi of New London while still maintaining hurricane force ($\geq$64 kt) winds. During July and August (Figure VIII-10) the axis is still to the southwest overland but splits near South Carolina with the primary threat thence from the Bahamas. The source for almost all July/August threatening tropical cyclones is the subtropical North Atlantic. Most threat storms from July through September recurve over water, passing New London to the southeast. The threat axis of probability has shifted completely

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[4]Track information was obtained from National Climatic Center, Asheville, NC.

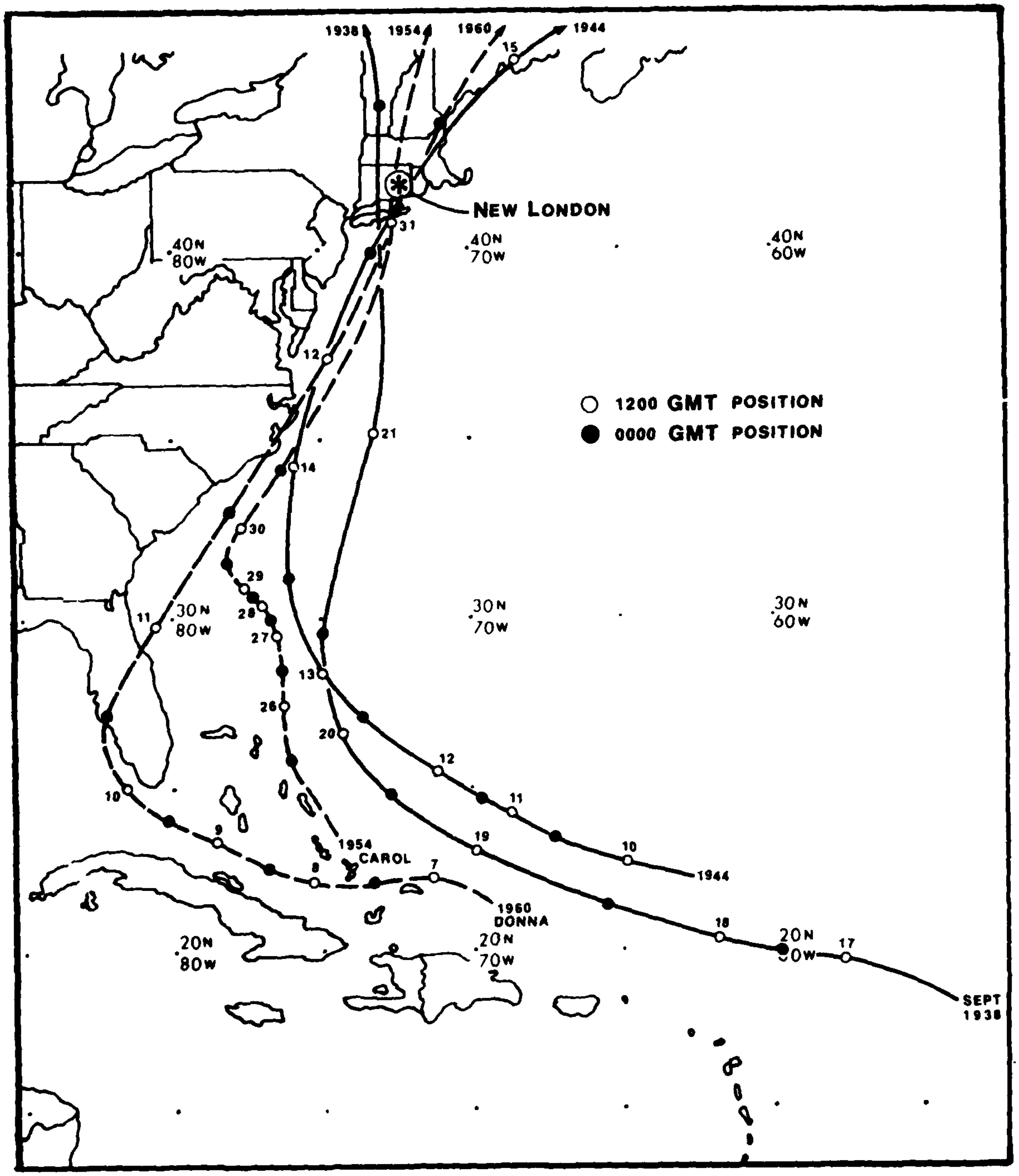

Figure VIII-7. Examples of fast-moving hurricanes that impacted New London area.

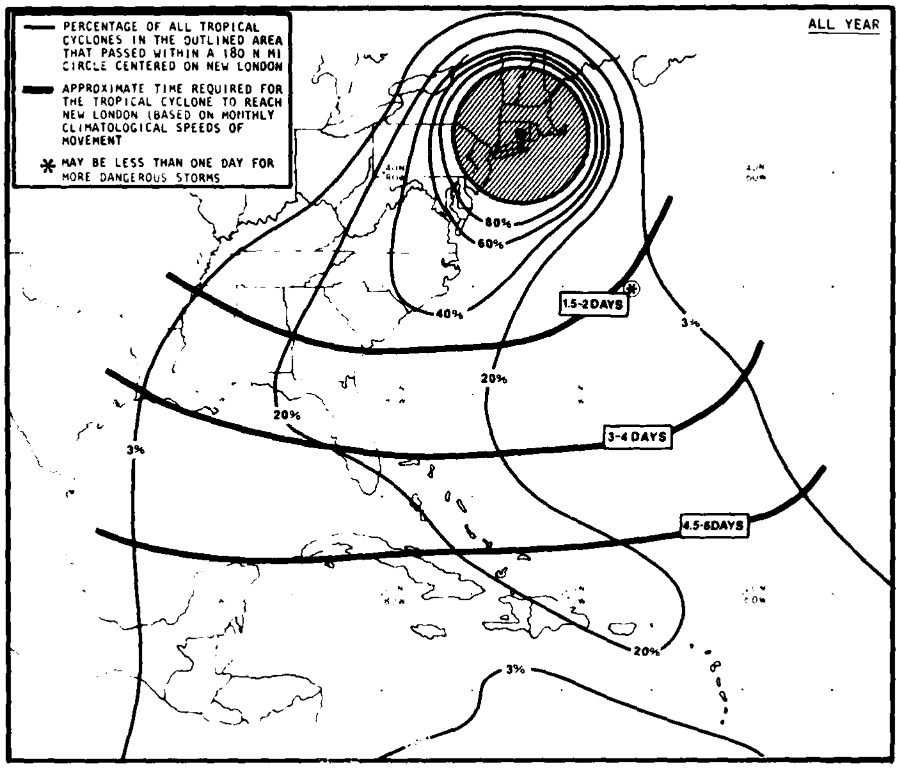

Figure VIII-8. Annual probability that a tropical cyclone will pass within 180 n mi of New London (based on data from 1871-1979).

offshore by September (Figure VIII-11) with most storms originating in the North Atlantic. September offers the greatest potential for a high speed northward moving storm to threaten the area.

For the period 1899 to 1979, 24 tropical cyclones were still at hurricane strength at their closest point of approach to New London. Of these 24 hurricanes, 5 passed to the west, and 19 passed to the east of New London.

The times to CPA presented in Figures VIII-8 through 11, should be used with caution since it is not the average but the exceptionally fast moving storm which is of the greatest danger to New London. For example, Figure VIII-11 indicates that a September storm located near 27N/74W should reach New London in about 3 or 4 days, based on climatology. However, the 21 September 1938 hurricane is believed to have traveled this distance in about 30+ hours (refer to Figure VIII-7).

Typical speeds of movement for hurricanes within 180 n mi at CPA varies from 25-30 kt for those crossing near the New England coast to 20-25 kt for those passing offshore to the southeast.

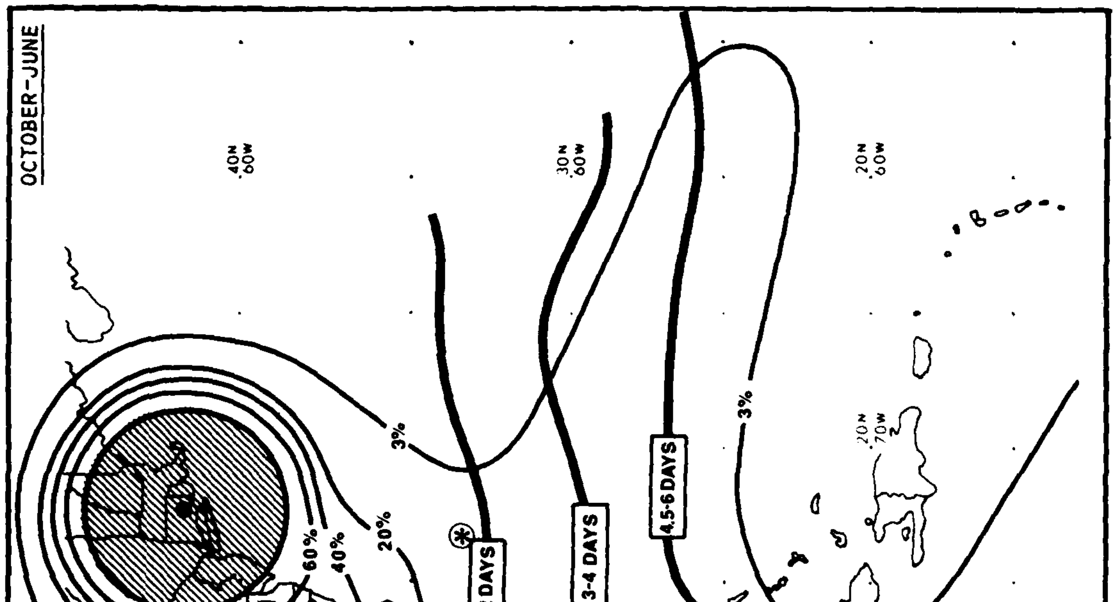

Figure VIII-9. Probability that a tropical cyclone will pass within 180 n mi of New London during the months of October-June (based on data from 1871-1979).

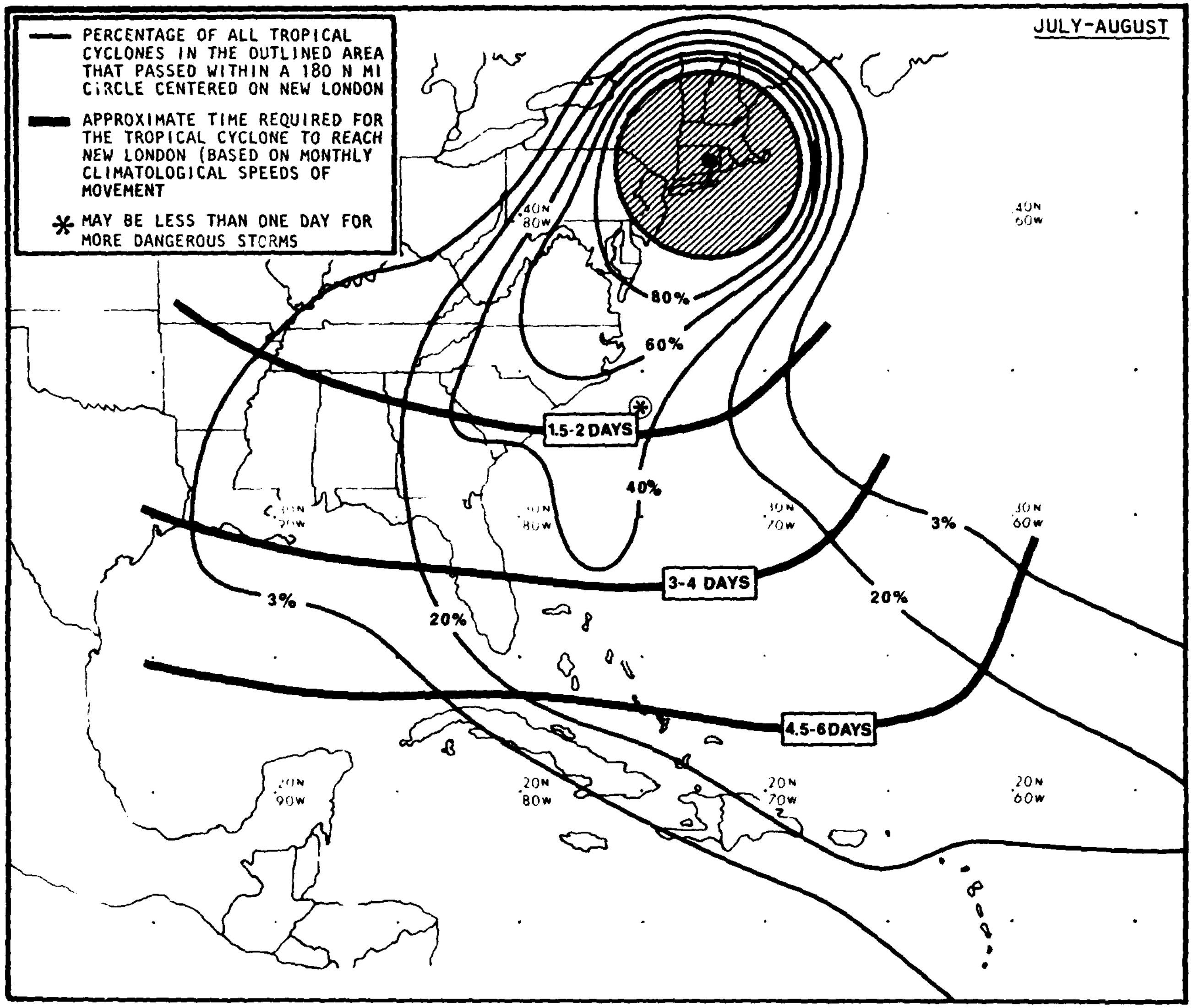

Figure VIII-10. Probability that a tropical cyclone will pass within 180 n mi of New London during July and August (based on data from 1871-1979).

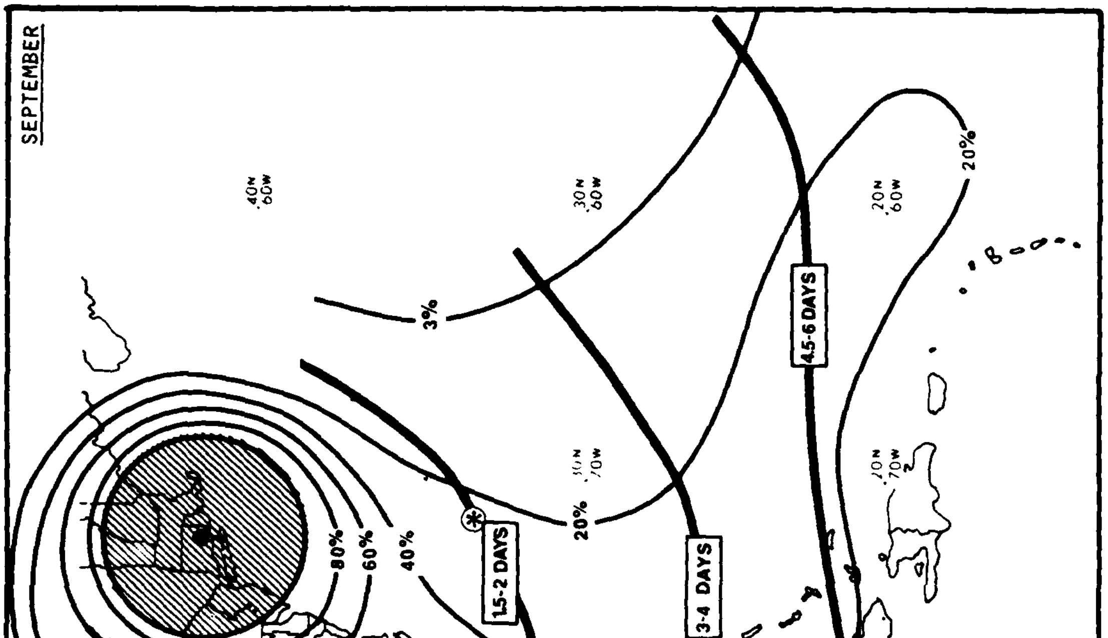

Figure VIII-11. Probability that a tropical cyclone will pass within 180 n mi of New London during September (based on data from 1871-1979).

Historically, the months of late August, September and early October are the greatest threat months for a direct over-water approach to New London. This period would coincide with the optimum time for the simultaneous occurrence of the following factors:

(1) Greatest tropical cyclone activity,

(2) Strong North Atlantic subtropical high pressure system,

(3) Deep atmospheric upper level trough lying over the East Coast.

These factors can combine to modify the normal recurvature of a tropical cyclone and instead accelerate and steer it rapidly north from Cape Hatteras into southern New England, along the eastern edge of a trough between two high pressure ridges. Unfortunately for New England, such storms lose little energy as they traverse the colder water between the north wall of the Gulf Stream and Long Island. This may be explained by their adoption of extratropical characteristics at higher latitudes or by their reduced interaction with the surface at such high speeds of advance. Either way, the circumstances described above combine to present a serious threat of destruction in southern New England.

4.2 WINDS AND TOPOGRAPHIC EFFECTS

Wind records for the area date back to 1950 for the Groton Airfield and the Groton Water Filtration Plant. These records were found to be incomplete. Wind records for the Groton Airfield were missing for most tropical cyclones due to station closure. Wind records were not available for the harbor area or the submarine base. In addition to the sparse Groton records, more complete wind data was obtained for the following relatively nearby locations:

(a) Quonset Point, Rhode Island (1944-1979)

(b) Block Island (1933-1979)

(c) Fishers Island (1932-1945)

(d) New Haven, Connecticut (1932-1979)

(e) Point Judith, Rhode Island (1944-1979)

These records are not totally complete, but do provide a better estimate of local winds. During the 39-year period (1932-1981) only three hurricanes (1938, 1944, 1954) have produced what can be estimated as hurricane force ($\geq$64 kt) wind in the New London area. Hurricane Donna of 1960 produced what are estimated to be strong gale or minimum hurricane force (55-65 kt) winds in the New London area. Estimated winds for New London for 1938 are 78-87 kt; for 1944 are 65 kt, and for Hurricane Carol of 1954 are 70-78 kt. These estimates are for exposed coastal locations. Gale force winds are estimated to have occurred more frequently, but are not a major problem in the semi-sheltered New London Harbor.

Because of its location in a sharply defined narrow river valley, New London harbor has considerable topographical shelter from most wind directions. The western portion of the lower harbor is, however, rather exposed to hurricane force winds from the southeast and south, particularly from Winthrop Cove southward (see Figure VIII-2). This was confirmed by the considerable damage inflicted by the 1938 hurricane. The New London "official" anemometer (location unknown)[5] indicated 85 kt of wind before the cups were carried away. Fishers Island reported an east wind of 91 kt. A 300-ft 5-masted barkentine, the "Marsala", dragged two anchors (one 8 and one 10-ton mushroom) while anchored off Shaw Cove. The 1057-ton Lighthouse Tender "Tulip" was carried ashore, by the combined effects of wind and surge, so that its bow was left atop the railroad tracks in front of the New London railroad station (see Figure VIII-2). The harbor and the Thames River are a natural channel, north and south, for the funneling of hurricane force winds. The NAVSUBASE and Coast Guard Academy piers are particularly exposed to the north winds that occur in the less dangerous semicircle of a northward moving hurricane. The main harbor, and, to a lesser degree, the NAVSUBASE are exposed to southerly winds for a short duration as a storm passes. However, the NAVSUBASE is well protected from the most dangerous northeast through southeast winds.

Figure VIII-12 illustrates portions of the track of major hurricanes which have affected New London. Historically, since 1871, the most destructive hurricanes have made landfall to the west of New London along the Connecticut coast. The lone exception would be the September 1944 hurricane which passed to the east hitting Rhode Island. Such approaches to the west of New London generally produce easterly winds veering to southerly. The topography around New London should significantly reduce the easterly components until the wind shifts to the southeast thus delaying the full impact of the storm. Wind records from New Haven, Connecticut indicate that the Long Island land mass tends to reduce winds for the New Haven area. However, this land mass does not seem to affect resultant wind strengths in the New London area.

4.3 WAVE ACTION

New London Harbor is well protected from wave action. Long Island and Fishers Island have significantly reduced the fetch for any seas which could enter New London Harbor and act as a barrier in protecting the harbor from deep ocean swell. Although a west wind can produce large seas in Long Island Sound, they are greatly reduced on entering the harbor channel.

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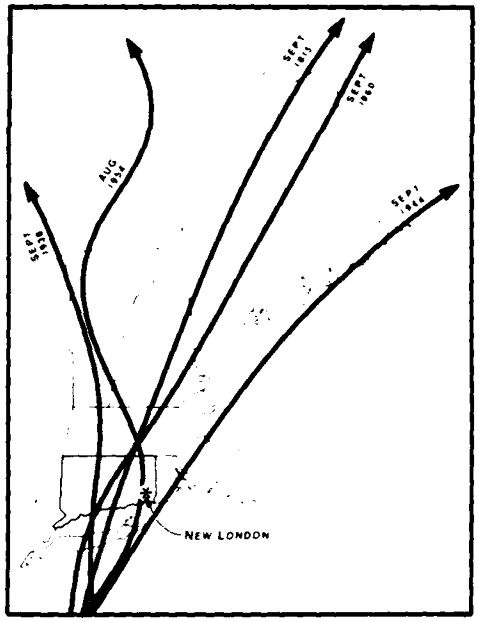
[5] A Wind to Shake the World, E. S. Allen, 1976.

Figure VIII-12. Major hurricanes affecting the New London area (1815, 1938, 1944, 1954, and 1960).



4.4 STORM SURGE AND TIDES

New London is one of the few major east coast Navy ports to have experienced a major storm surge in this century. The storm surge of 21 September 1938 hit New London as an apparent tidal bore (wall of water) causing considerable destruction. Storm surges from other storms have occurred fairly recently (1954, 1960), but these caused flooding only. The apparent occurrence of a tidal bore with the 1938 hurricane, rather than the more common flooding, is mainly attributable to the high rate of forward movement of this particular storm and probably accounts for the extensive damage to vessels and facilities in the lower harbor area rather than the effects of wind alone. Figure VIII-13 illustrates a tidal flood profile for New London Harbor and the Thames River. When applying historical high water marks to present day facilities, approximately one-half foot should be added to the NGVD values to account for the changing sea level since 1929. The 1938 surge was slightly greater than that expected once in a hundred years. It should be noted that the NAVSUBASE can expect about one foot more flooding than the main harbor. The area above the bridges escapes the destructive kinetic effects of storm surge but is not immune to the flooding associated with a hurricane strike. The constriction at the bridges and the widening above the bridges limit the energy passage through the gap. During the 1938 hurricane a 100-ft two-masted schooner was sunk at the

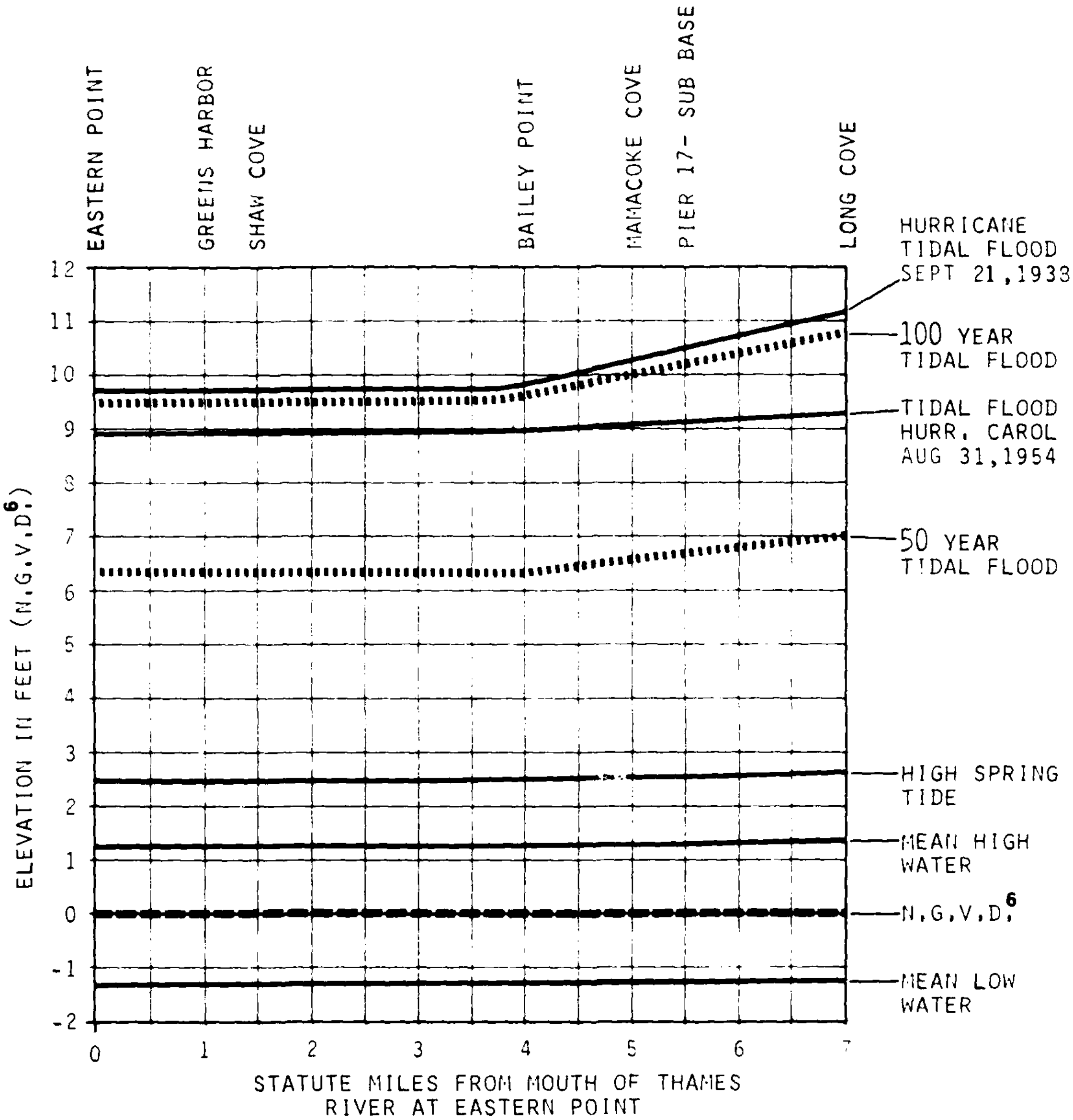


Figure VIII-13. Tidal flood profile of the lower Thames River (U.S. Army Corps of Engineers, January 1980).

[6] National Geodetic Vertical Datum; approximates to mean sea level. Add 0.5 ft to allow for rise in sea level since 1929.

Coast Guard Academy docks after being battered by strong winds. The NAVSUBASE sustained mainly water damage from this storm, along with minor damage to piers and the sinking of a floating crane (YD). The evidence suggests that although the NAVSUBASE area experienced some flooding during the 1938 hurricane strike, the highly destructive impact of the "tidal bore" had been absorbed much further down river and that the crane and schooner were submerged by taut mooring lines.

Astronomical tides are of limited concern in New London other than their timing relative to the occurrence of a storm surge. The 1938 storm surge occurred about 2 hours before predicted high tide, thus causing a storm surge to be added to an almost high tide. The tidal range at State Pier is only about 2.6 ft from mean high water to mean low water. The most recent tide tables should be consulted for exact values. River currents, although strong on the ebb, are not of major concern since tugs are routinely required for all submarine docking and undockings.

5. THE DECISION TO EVADE OR REMAIN IN PORT

Specific instructions to Navy ships for dealing with heavy weather at New London are found in COMSUBGRU TWO/IAC NLON OPORD 2000, Appendix 5 to Annex C. This is the only document that delineates actions to be taken as each hurricane condition is set. Evasion rationale should be based on consideration of four general factors:

a. Vessel characteristics
b. Harbor conditions
c. Most recent hurricane warning forecast
d. Storm climatology

Individual vessel factors are best determined by those responsible for each vessel. Interpretation of harbor and climatological factors are addressed in the following section.

5.1 EVASION RATIONALE

(a) In the event that a hurricane is forecast to strike the southern New England area, the general rationale applicable to New London main harbor (south of the main bridges), is for all seaworthy vessels to leave. This rationale is based on the high probability of significant storm surge, low pier deck heights at most locations, and the general lack of anchorages suitable for use during hurricane conditions. The USS FULTON is the lone exception since, with its older riveted hull and slower speed, it would be more susceptible to damage in attempting to ride out a hurricane at sea. Above the highway bridges in the Inner Harbor, the rationale is for submarines to remain at NAVSUBASE berths and

some other smaller vessels to anchor in the river above the bridges. This rationale is based on the expected reduction in storm surge energy above the bridges (see Section 4.4), topographical sheltering from winds by higher terrain and the unique features of a round submarine hull in contact with an adequate pier.

(b) Timing of any evasion from New London is extremely critical. It can be expected that in the event of a storm such as the 1938 hurricane, New London could go from readiness condition IV to condition I in a matter of a few hours. It should be noted from Figures VIII-8, 9, 10 and 11 that the climatological position for the average storm 48 hours from New London is near the latitude of Charleston, SC, while the mean 72-hour position would be a latitude not too far south of Jacksonville, FL. However, an examination of Figure VIII-7 shows the following approximate times to landfall in New England from the latitude of Charleston:

(1) 21 Sep 1938 - 14 hours
(2) 15 Sep 1944 - 20 hours
(3) Carol 1954 - 22 hours
(4) Donna 1960 - 24 hours

Submarines require approximately 8 to 12 hours to complete a dispersal to safe submergence waters. It becomes obvious that in the case of the 1938 storm, sortie for submarines to safe submergence would not have been likely even with the best warnings. For the other 3 storms, 20 to 24 hours was available which would have allowed some opportunity to clear port and reach safe operating depths. A further hazard would be sea conditions ahead of such storms which may not allow even the hours noted above. Fortunately, hazardous sea conditions are not as bad ahead of a fast moving storm as those associated with larger slow moving hurricanes. For surface vessels, evasion to the southeast involves crossing the track (T) if the hurricane typically recurved to the northeast over water. Evasion straight east is not reasonable because the sortied ship could possibly be put in the position of trying to outrun a fast moving hurricane in a following situation. Evasion to the west is an option because of the limited shelter offered by Long Island Sound. A vessel could also anchor in Long Island Sound (see Section 3.3); an option recommended by some local port authorities, although no records were found of Navy ships anchoring in the Sound. Hurricanes, in a position of being a threat to New London, are far enough south to actually take any one of many tracks. They could pass inland south of New York, they could hit the Connecticut/Rhode Island coast, they could pass near Cape Cod or they could recurve well offshore to the southeast. In most cases a sortie decision will have to be made before the storm is committed to any particular track. If a hurricane is obviously threatening to make landfall along the New England coast to the west of New London (see Figure VIII-12), then immediate

sortie to the southeast is the obvious reaction for all vessels (including submarines) except those at suitable berths upriver.

(c) Storms approaching from overland or mostly overland are of limited threat due to their reduced intensity and would not justify evasion. These storms should not generate significant storm surge and with the topographical protection at New London winds would be of limited consequence.

(d) Hurricanes approaching over water between the east coast and the meridian at 70^{0} west should be treated as a potential threat. If the forecast moves these well offshore to the south and east, then sortie is not considered necessary. However, if the forecast is for a more northerly track, then sortie and/or reberthing is essential. In the event of a major tropical cyclone posing a threat to the New London area, the nest of submarines at the USS FULTON should be ready to move on short notice.

5.2 EVASION AT SEA

For surface vessels evasion at sea includes moving to Long Island Sound where the sheltering from seas is quite effective. This option is not, however, available for submarines which must either reach safe submergence depths or remain in port. Also to submerge safely the submarine must reach its submergence point before seas and winds have become excessive. When evasion at sea is contemplated, the importance of correctly assessing the threat posed by the storm and acting quickly cannot be overemphasized. Each threat must be judged on its own merits but the following describes the most likely threat situations and recommended courses of action:

(a) <u>Tropical North Atlantic Hurricane Near the Bahamas</u> -- Tropical cyclones approaching from this sector in close proximity to the east coast are New London's greatest threat for the dangerous completely overwater approach. They are also the most likely candidates for rapid acceleration northward. The only sortie options from a threatening hurricane presently located near the Bahamas is either to evade within the confines of Long Island Sound or head east-southeast to southeast with intent to clear to the southeast side crossing the T. Heading directly east may not give enough clearance if the storm moves rapidly northeast. Since the majority of such storms do accelerate along a track in a northeasterly direction well south of Cape Cod, any sortie must be initiated early, otherwise the vessel can easily be overrun before it is clear. The submarine's problem is different since the main concern is to submerge safely in deep water before wind and seas exceed safe limits, i.e., the vessel does not need to pass beyond the storm's track but must get to a certain point before the fringes of the tropical cyclone can impact on the area. It is approximately 100 n mi from New London Harbor to the closest position of the

100 fathom contour. For a fast forward moving (30+ kt) storm, the seas and most wind will not project out ahead of the storm, whereas in the case of the slower moving storm, swell extends for considerable distances from the storm's center. The surface unit can tolerate various degrees of seas and winds in circumnavigating the hurricane. If the storm becomes one of the unique, dangerous to New London, northward accelerating hurricanes, less time is available to sortie since the schedule will be compressed but it will be easier to clear to the east of the storm. In any event if a unit intends to sortie to deep water, an early decision must be made, preferably with the storm no closer climatologically than 48 hours. Hurricanes from near the Bahamas which actually strike the southern Atlantic coastline of the United States would not generally require a sortie since they historically weaken considerably. An exception would be those hurricanes which pass over a small area of land, particularly Cape Hatteras, such as Hurricane Donna in 1960.

(b) Tropical North Atlantic Hurricanes (farther northeast of Bahamas) -- Based on records of this century, tropical cyclones north of approximately 27°N latitude and east of about 70°W longitude have a low probability of being a destructive threat to New London. These storms do not generally warrant a sortie. However, for a major hurricane in this area predicted to threaten New London, evasion may be required. Since in this case the most probable direction for storm travel is north-northeast, if the warning is not correct, the best evasion route would be to travel southwest along the U.S. east coast. Extreme caution should be used being aware that the vessel may be boxed in against the coast by a storm unexpectedly heading in a more westerly direction.

(c) Gulf of Mexico and West Caribbean Hurricanes -- Tropical cyclones approaching from this area have a fairly high probability of passing within 180 n mi of New London, but they generally must pass overland first. These storms, that have weakened overland, are not considered a threat to shipping and would not generally require evasion at sea. An exception might be if such a storm entered the Atlantic near Florida/Georgia and reintensified. In such rare cases crossing the T toward the southeast would be the recommended course, being aware that there is a distinct possibility of being overtaken by an accelerating storm.

5.3 REMAINING IN PORT

When there are indications that a hurricane may accelerate along an over-water track leading to landfall along the south coast of New England, then evasion at sea is the recommended course of action for all seaworthy deep draft surface vessels and any submarines, especially the SSBN 726 class, that would otherwise be berthed in the main harbor. When a lesser threat exists, or if sudden unexpected storm intensification/acceleration makes sortie hazardous, then some local main harbor berthing (State Pier, NUSC pier 7) may be used as a last resort for submarines (i.e., those vessels which cannot be accommodated at the NAVSUBASE).

The final decision to remain in port at New London will depend on many parameters, including port loading, pier availability at the NAVSUBASE, the potential threat (wind and surge), and most importantly, the expected time of arrival of the storm. The following considerations pertain:

5.3.1 State Pier, USS FULTON

In the event of a possible strike by a tropical cyclone of hurricane proportion, the nest of submarines at State Pier must be broken up. Available berthing at the NAVSUBASE should be used by all classes of submarine other than the Trident armed Ohio Class vessels which are too deep drafted to gain access to the Base with the existing channel project depth up river. There is room at berths 2 and 3 of State Pier which could be used as a last resort to accommodate two 640 class or earlier submarines as an alternative to evasion at sea. These berths are exposed to surge but are somewhat sheltered from a north or south wind. The Mediterranean moored USS FULTON should remain alone at the dolphins with both port and starboard anchors out. In the event of a hurricane threat, it is recommended that extra bow lines be run from the FULTON to State Pier to ease the set onto the dolphins by a southerly wind since the FULTON has a large sail area exposed to north and south winds. Although space for another vessel is available at the dolphins, this is not recommended because of the additional strain that would be imposed. All vessels at State Pier must be alert for the rapid rise associated with storm surge, with mooring lines rigged so they may be tended from the vessel since the pier or dolphin may be flooded. Since little warning time may be available, vessels should be prepared to react quickly, particularly in the case of an intense, fast moving hurricane predicted to pass nearby. Although the Navy side of State Pier is fairly well protected, vessels should be alert for drifting wreckage with a strong south wind.

5.3.2 Navy Submarine Base

The NAVSUBASE is considered to be a hurricane haven for submarines moored properly at concrete piers. Considering the round shape of the submarine hull and the prescribed method of mooring the vessels with wires boat-to-boat across the pier, these berths are adequate for submarines. Mooring instructions are well defined in COMSUBGRU TWO/IAC NLON OPORD 2000. For a severe hurricane making landfall nearby, complete inundation of the piers, to possibly 3 or 4 ft above deck height, should be expected. Further, many of the base facilities nearest to the piers (Lower Base) may also be flooded leading to a disruption of shore services. It is anticipated that surface vessels (ASR, YD, YTB) will also be moored at the NAVSUBASE. In a severe storm with an extreme surge these vessels may experience difficulties handling a combination of strong winds and a flooded pier. In the case of the ASR, the best course of action may be to anchor north of the highway bridges where there would be adequate room for maneuvering and storm surge would no longer be a threat. The floating drydocks should be flooded down to reduce their sail area with ships undocked if possible.

5.3.3 NUSC Pier

Although a substantial pier with excellent deck height and depth alongside, the north side of pier 7 should be used only as a last resort for hurricane berthing. Although sheltered somewhat from wave action by NUSC pier 4, it is exposed to the strong southerly and southeasterly hurricane winds, the full energy of a storm surge entering the harbor and damage from drifting wreckage and debris. The NUSC pier is not recommended for hurricane berthing except in an emergency -- only to be used for submarines unable to sortie or find shelter up river.

5.3.4 Coast Guard Station

The Coast Guard Station pier is not recommended for hurricane berthing.

5.3.5 Electric Boat Shipyard

Although susceptible to flooding because of low pier deck heights, this facility is well sheltered from northeast and east through southeast winds. Vessels afloat should be moved to the most protected berths in the yard. It is unlikely that better shelter can be provided for Ohio Class submarines elsewhere in the Thames River but some consideration should be given to moving smaller submarines to the NAVSUBASE. Of particular concern, at the shipyard, would be

the barges with ships company living aboard, waterborne new construction ships that are unmanned and those ships in drydock. With a 10+ ft storm surge these particular units are susceptible to substantial damage if lines are not tended and if watertight integrity is not established.

5.3.6 Hess Dock

Hess Dock, although aligned north-south, is quite exposed to southeast and south winds. Its location just inside the harbor entrance also exposes the dock to storm surge energy as well as inundation of its 8-ft deck height. Although substantially constructed it is not recommended for hurricane berthing.

5.3.7 Coast Guard Academy Pier

With its exposure to north winds and storm surge inundation, it is recommended that the EAGLE and any Coast Guard Cutter at the pier be moved to anchorage in the river near the Academy.

5.3.8 Use of Anchorages

There are no deep draft anchorages available in New London Harbor. Long Island Sound can be used as a deep draft anchorage. Designated anchorage A could be used as a last resort for smaller vessels. The proposed hurricane anchorage as recommended in Section 3.2 is the river above the twin highway bridges. Although not verified, vessels anchored here could expect 90+ peak gusts from the north with a severe hurricane.

5.4 RETURNING TO HARBOR

After the passage and successful evasion of a hurricane, returning to the harbor may present hazards. There may be wrecks in the channels, large floating debris, and damage to the piers. Alongside services may well be disrupted by the flooding associated with storm surge. There is a very high probability that channel markers and other navigation aids have shifted position or have become otherwise unreliable.

5.5 RUNNING FOR SHELTER

Coast Pilot II states that "New London Harbor, . . . is an important harbor of refuge" and that "vessels of deep draft can find anchorage here in any weather and at all seasons". Such advice is sound for winter storms and for hurricanes

not expected to landfall along the southern New England coast, but not for severe hurricanes expected to pass nearby, especially to the west of New London. Ships at sea off the coast of New England may consider using New London to escape the effects of a hurricane with the following considered:

(1) Draft restrictions exist north of the main bridges, shallower draft vessels can find shelter there.

(2) Berths at the NAVSUBASE can only be allocated to military units after prior coordination with COMSUBGRU TWO. Space may be very limited.

(3) Submarines at sea, able to submerge, are better off at sea.

5.6 ADVICE FOR SMALL CRAFT

Small craft should be either removed from the water above projected flood levels or moved up river. There are no recommended small craft hurricane mooring facilities in the main harbor. During the 1938 storm vessels at Greens Harbor piled ashore or drifted up the harbor, while vessels at Shaw's Cove beat against each other. Up river, small craft should be bottom moored, considering protection from a north or south wind. The area above the bridges is subject to the possibility of 11+ ft of storm surge, suggesting a large scope in any mooring line. Exceptional anchor weights will be required for strong winds, even in semi-sheltered areas. Also suitable berthing could be found in Mamacoke or Smith Cove. Another possibility is to anchor out at Thames Shipyard. If time permits, the best location for small craft would be close to Norwich but the rock dikes along the way are dangerous for those not experienced at navigating this section of the river.

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IX. NEWPORT, RHODE ISLAND

-- TO BE PUBLISHED --

X: CONTENTS

X. PENSACOLA, FLORIDA

SUMMARY

Pensacola is a frequently used U.S. Navy port. The aircraft carrier LEXINGTON and destroyer OWENS are home-ported at Pensacola Naval Air Station. The civilian port of Pensacola is a busy and growing commercial shipping terminal which handles vessels with draft to 30 ft as well as small craft engaged in a variety of marine transportation and service activities.

History has demonstrated that the hurricane season presents a very real and serious threat to Navy and commercial marine activities at Pensacola. Pensacola has been affected by tropical cyclone activity at an average frequency of 1.3 events per year. One out of 4 tropical storms/hurricanes passing within 180 n mi of Pensacola have caused sustained winds greater than 33 kt in Pensacola Bay. One out of 7 tropical storms/hurricanes entering this threat area have caused winds gusting to hurricane force.

The hurricane season is late May through early November. September is by far the major threat month. The principal threat to Pensacola is from tropical cyclones approaching from the southeast, south and southwest. Seventy-three percent of all tropical cyclones entering the 180 n mi critical area in the 109 year period between 1871-1979 approached from these sectors.

Pensacola's location in the hurricane belt and the absence of sheltered facilities and anchorages available to deep draft vessels in Pensacola Bay render it a poor hurricane haven. It is recommended that deep draft vessels evade at sea when Pensacola is threatened by an intense tropical storm (winds greater than 47 kt) or hurricane (winds greater than 63 kt) approaching from the Gulf of Mexico. Early threat assessment is essential due to the elapsed time required to reach open water and the limited number of evasion routes in the Gulf of Mexico. Anchoring in Pensacola Bay is an alternative that should be given serious consideration in certain marginal and secondary threat situations.

Advice to small craft is to remove the craft from the water. Otherwise, seek shelter in one of the many bayous, slews, creeks, and rivers that border on Pensacola, Escambia, Blackwater, and East Bays.

This hurricane haven evaluation was prepared by R.E.Wrenn of Ocean Data Systems, Inc. (ODSI), Monterey, CA 93940.

1. LOCATION AND TOPOGRAPHY

As shown in Figure X-1, the Port of Pensacola is located on the north side of Pensacola Bay in the far west of Florida. The bay is about 13 miles long and 3 miles wide with depths of 20 to 50 ft. The bay is separated from the Gulf of Mexico by Santa Rosa Island, a long and narrow strip of white-sand beach and dunes. Although some of the dunes reach a height of about 15 ft the elevation of the barrier beach generally is less than 10 ft. Santa Rosa Sound, part of the Gulf Intracoastal Waterway, lies between Santa Rosa Island and the Gulf Breeze Peninsula which extends westward into Pensacola Bay. Elevations on this peninsula are mainly below 25 ft, averaging 15 ft. Escambia Bay, Blackwater Bay and East Bay connect Pensacola Bay to the northeast and east. Much of the terrain on the western shore of Pensacola Bay, the site of the Naval Air Station and the town of Warrington, is below 25 ft. To the north of the Port of Pensacola the terrain is hilly, rising abruptly to 50 ft just inland and to 100 ft in the rural sections of Pensacola City.

The entrance to Pensacola Bay, shown in Figure X-2, lies between Fort Pickens on the western tip of Santa Rosa Island and Fort McRee on the eastern tip of Perdido Key. The entrance is approached by Caucus Channel, a 37 ft deep cut dredged through shoals to the south of the coast. Beyond Caucus Channel lies a large turning basin 33 ft in depth (October 1979[1]). From the basin, Figure X-2 shows Bay Channel extending northeast for about 4 miles to West Channel and East Channel, both dredged to 33 ft. These channels permit expeditious transits between the inner harbor and bay without tug assistance.

No bridges cross Pensacola Bay between the entrance and the city of Pensacola. The Pensacola Bay Bridge, seen to the far east in Figure X-2, is a highway causeway having a fixed span with a horizontal clearance of 125 ft and a vertical clearance of 50 ft.

2. PORT AND HARBOR FACILITIES

2.1 BERTHS FOR DEEP DRAFT VESSELS

In the Port of Pensacola (Figure X-3), all the deep-draft facilities are at the head of East Channel. The facilities are owned by the City of Pensacola and operated by the Port of Pensacola. In general terms there are five deep-draft berths with 35 ft alongside and a deck height of either 11 ft or 11 3/4 ft. More complete details of these deep-draft berths (and 20 other berths) are to be found in Port Series 19 published in 1979 by the U.S. Army Corps of Engineers. This publication also provides details of 13 diesel-operated tugs and towboats, ranging from 150 to 1800 horsepower, used for towing, docking, undocking and shifting vessel at the Port of Pensacola.

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[1] See Notice to Mariners and most recent charts for controlling depths.

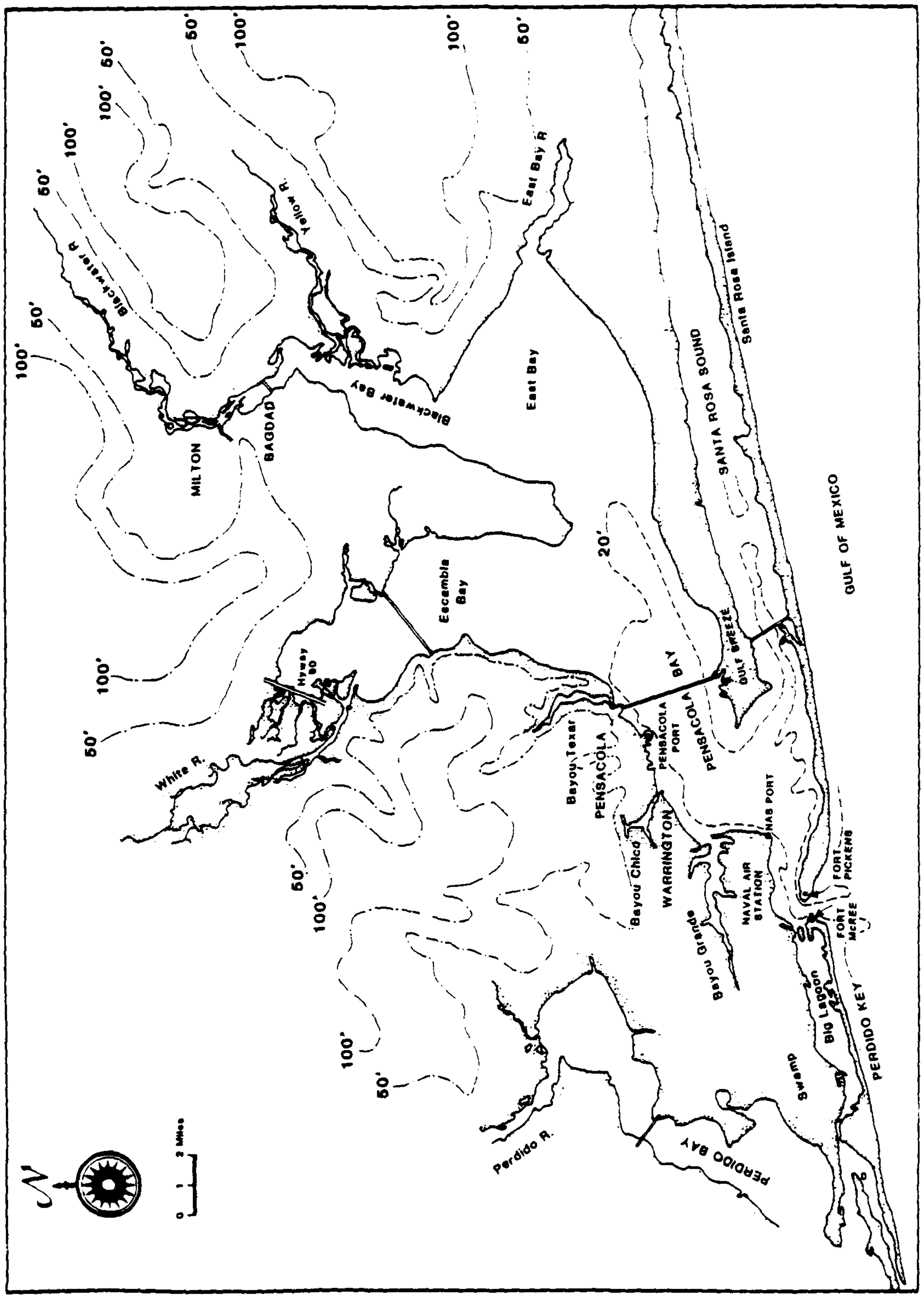

Figure X-1. The greater Pensacola Bay area.

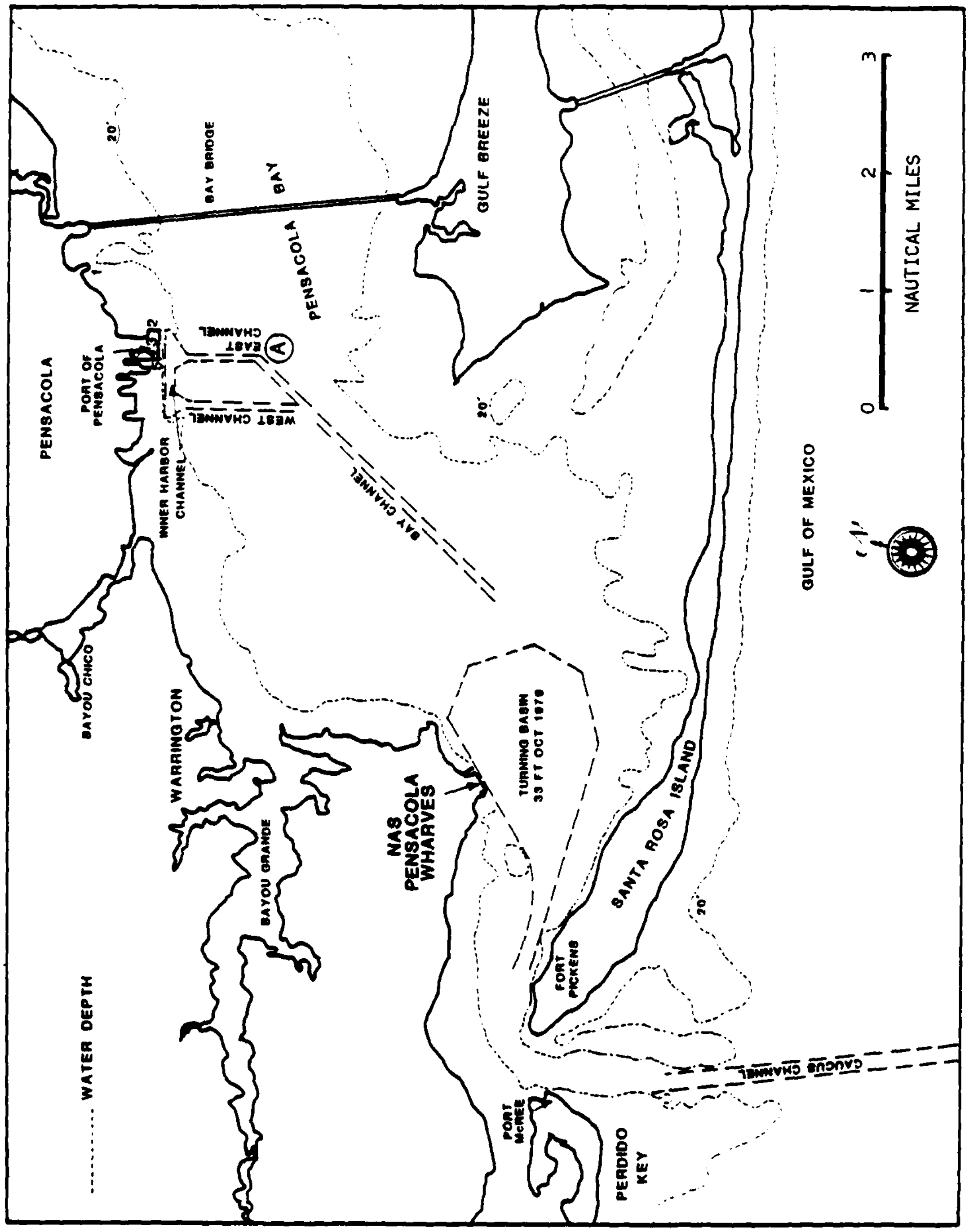

Figure X-2. Pensacola Bay and approaches.

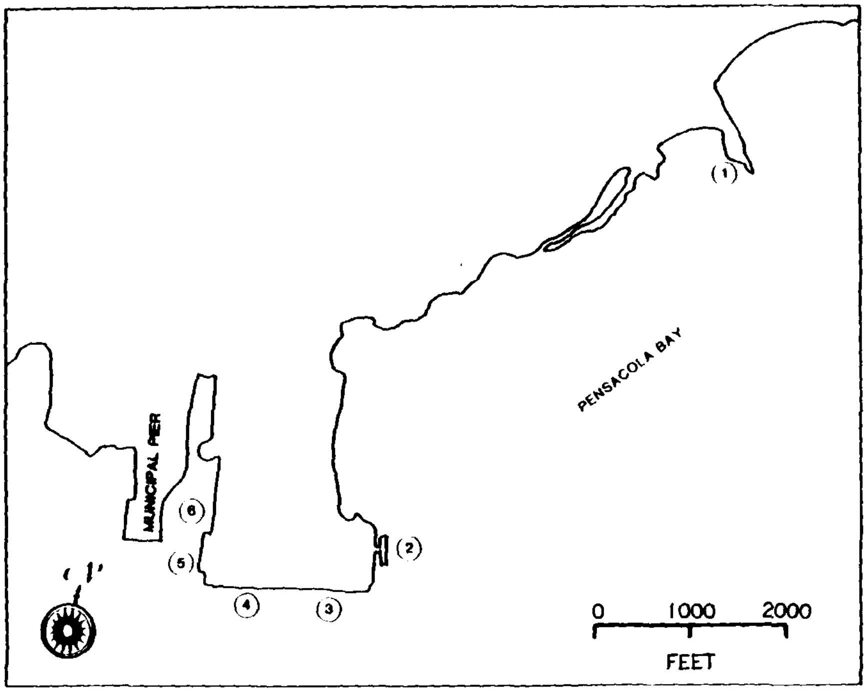

Figure X-3. The Port of Pensacola.

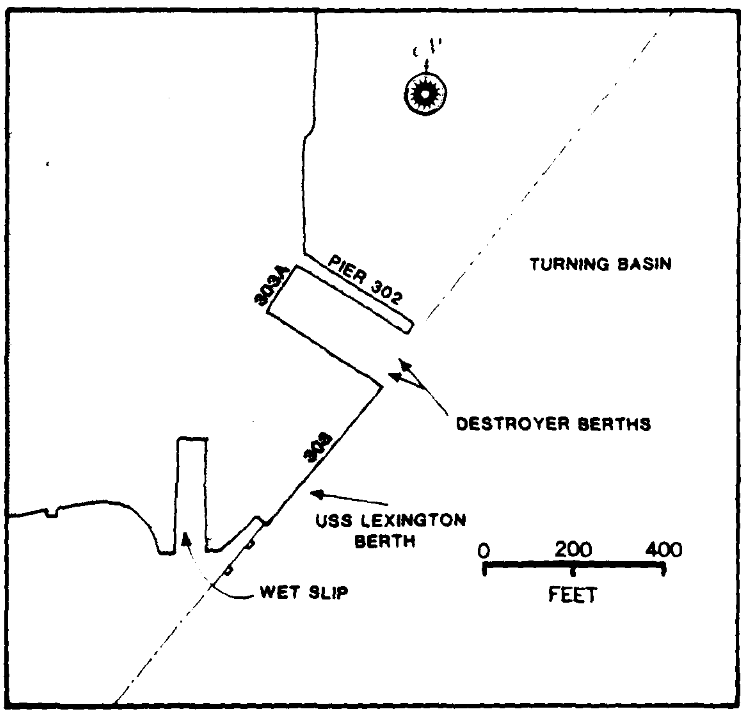

Figure X-4. Naval Air Station Port, Per.,acola.

Facilities at the Naval Air Station (NAS) are located along the northwest edge of the tuning basin (Figure X-2). A more detailed map of this region is shown in Figure X-4. Pier 302 has an alongside depth of not less than 25 ft to the southwest, and Wharf 303, otherwise known as Allegheny Pier, has an alongside depth of not less than 35 ft; the deck height in either case is 11 to 12 ft. For small boats there is a wet slip a little to the west of Wharf 303. The U.S. Navy maintains 6 tugs, usually tied up in the basin formed by Piers 302 and 303A for servicing the aircraft carrier and destroyer normally based at NAS Pensacola. The aircraft carrier uses Allegheny Pier and the destroyer uses Pier 302.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Port of Pensacola berths 1 through 6 (Figure X-3) may be designated Safety Zones, in accordance with Title 33 Code of Federal Regulations (CFR) 165 (Safety Zones), when hurricane force winds are possible within 24 hours. When so designated vessels may not enter into or transit therein without permission of the Harbor Master/Port Director.

Deep-draft vessels require tug assistance for docking and undocking. The tugs for this purpose, and for making cold or assisted moves, are available only on advance notice. (The towing companies in the area specialize primarily in towing through the Intracoastal Waterway.) In view of the likely demand when heavy weather is expected, tug services may not be available unless arrangements are made in good time.

If the expected heavy weather is such that a decision is made to go to anchor, the usual anchorage is off the City of Pensacola where the holding ground is good. This position is marked with the letter "A" in Figure X-2. In addition, good anchorage can be found in any part of the bay except south of the Naval Air Station. Pensacola Anchorage, outside the Bay, just east of the safety fairway is a designated anchorage (U.S. Coast Pilot 5, 1980).

In the event of damage, facilities are available for making many repairs to hulls and machinery. However, facilities are not available for dry-docking large deep-draft vessels or for making major repairs to such vessels.

2.3 FACILITIES FOR COASTAL AND IN-SHORE VESSELS

For commercial shipping and fishing vessels, Pensacola has more than 25 wharves and piers. Very comprehensive facilities are available for coastal and in-shore vessels, and for recreational small-craft, including repairs to hulls and machinery, bunkering, gasoline, diesel fuel, water, ice and marine supplies. The City of Pensacola Municipal Pier, East Side, provides moorings for the

U.S. Coast Guard vessel and sport fishing boats; the Municipal Pier, West Side, is used for sport fishing boats and recreational craft. A limited number of berths for transients may be found in Bayou Chico and elsewhere.

The Naval Air Station provides, or can arrange, all necessary facilities for supporting U.S. Navy vessels visiting or stationed at Pensacola.

Although larger ocean-going vessels are generally in less danger at sea than in harbor when under hurricane threat, the reverse is true for small vessels. In general terms, four procedures are available for small vessels; secure to a wharf or pier, anchor, remove from the water, or seek shelter in one of the many bayous off Pensacola Bay, Escambia Bay or East Bay. These procedures are discussed in greater detail in Section 5.

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT PENSACOLA

3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect on Pensacola. However, the historical behavior of storms and their impact on Pensacola should not be regarded as a reliable *guide* to the detailed behavior and impact of a particular storm as it approaches the port.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Pensacola is considered to represent a threat to the port.

The outstanding feature of the U.S. gulf coast region is its location on the north shore of the Gulf of Mexico and its orientation perpendicular to normal tropical cyclone tracks as they move more or less northward out of the tropics. Also of importance is the region's position between 25 and 30 degrees north latitude which is within the normal locus of tropical cyclone recurvature which oscillates between latitudes 25N and 35N during the tropical cyclone season. This latter factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. During this phase of the tropical cyclone life cycle, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature, and obviously, the storm's precise future position at a point in time.

The "Hurricane Season" along the gulf coast is late May through early November. During the 109-year period between 1871 and 1979 there were 143 tropical cyclones that met the 180 n mi threat criteria for Pensacola, an average of 1.3 per year. The following table shows the monthly totals and percentages. These data are graphically presented in Figure X-5.

Month	Number	% of Total
May	2	1.4
June	18	12.6
July	16	11.2
August	22	15.4
Sept	56	39.2
Oct	27	18.9
Nov	2	1.4

Figure X-6 illustrates the 137 events as a function of compass octant from which tropical cyclones have approached Pensacola.[2] The numbers in parent[illegible] represent the percentage of cyclones from the sample approaching from a part[illegible]lar octant. This figure shows that the major threat sector extends from the southeast to the southwest.

It is significant to note that a small number of tropical cyclones developed within a *180 n mi radius* of Pensacola. Two developed quickly into hurricanes while in the threat area.

Figures X-7 through X-11 are statistical summaries of threat probability for the years 1871 to 1979. These summary data are presented in five charts, each representing data encompassing specific periods during the year. These periods are:

1. Tropical cyclones occurring during May and June.
2. Tropical cyclones occurring during July and August.
3. Tropical cyclones occurring in September.
4. Tropical cyclones occurring during October and November.
5. All tropical cyclones of record during the 109-year period.

The solid lines in these figures represent the "percent threat" for any storm location. For example, in Figure X-7, a tropical cyclone located over the northeast tip of Yucatan Peninsula has a 40% probability of passing within 180 n mi of Pensacola and will reach Pensacola in 48 to 72 hours (2 to 3 days). The dashed lines represent approximate approach times to Pensacola based on the climatological approach speed for a particular storm location.

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[2]Six tropical cyclones developed within 180 n mi of Pensacola and were at their closest points of approach at the time of formation. An approach direction is therefore not applicable to these six.

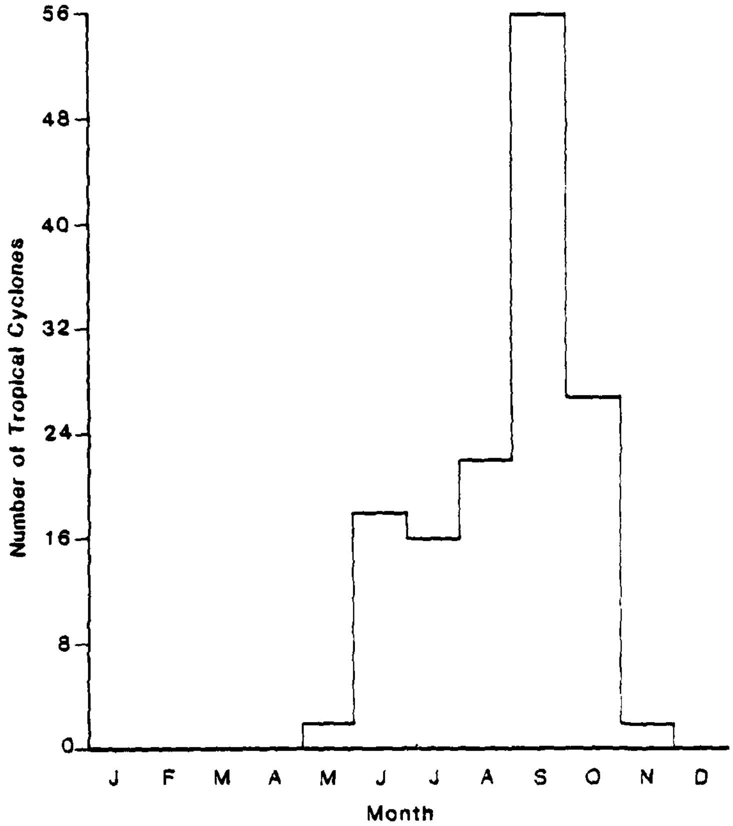
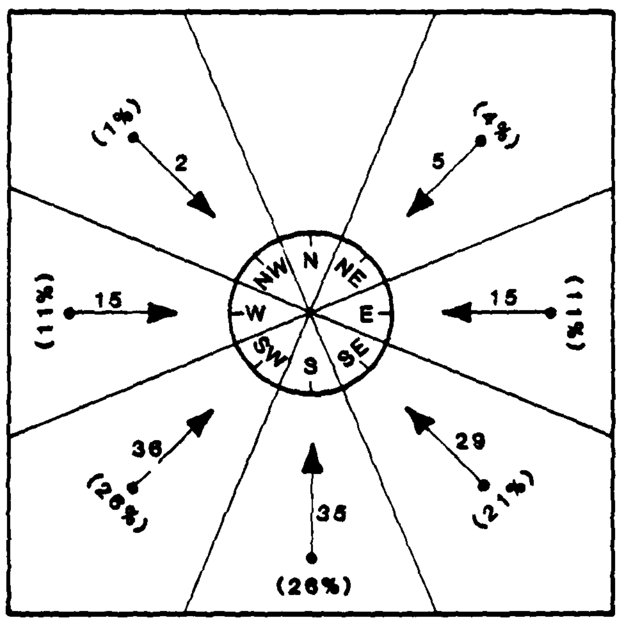


Figure X-5. The frequency distribution of tropical cyclones that passed within 180 n mi of Pensacola during the period May-November (based on data from 1871-1979).

Figure X-6. Direction of approach of tropical cyclones that passed within 180 n mi of Pensacola (based on data from 1871-1979). Numerals show the number of storms approaching from each octant; percentages in () are percent of total sample from each octant.



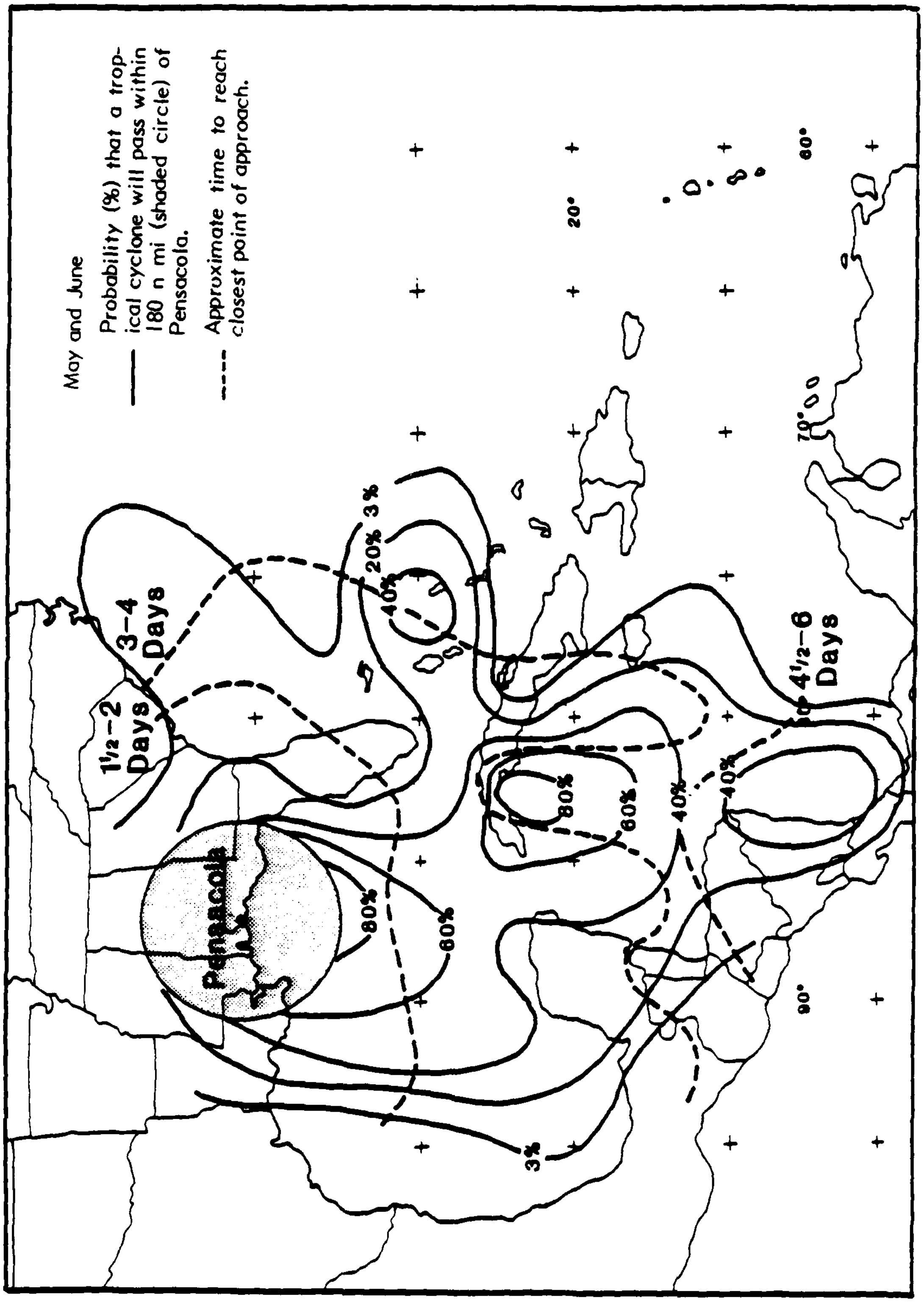


Figure X-7. Probability that a tropical cyclone will pass within 180 n mi of Pensacola during the months of May and June (based on data from 1871-1979).

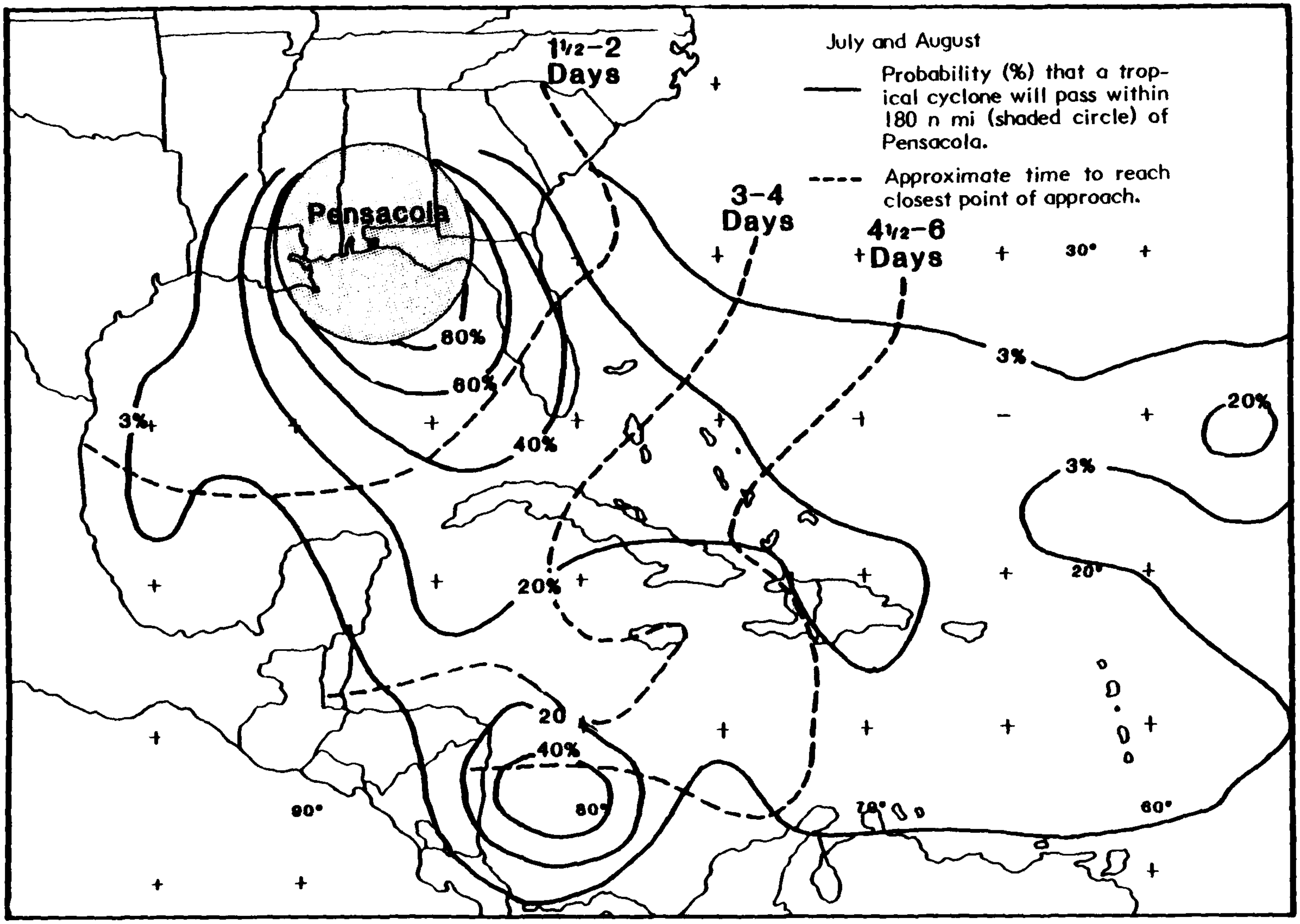


Figure X-8. Probability that a tropical cyclone will pass within 180 n mi of Pensacola during the months of July and August (based on data from 1871-1979).

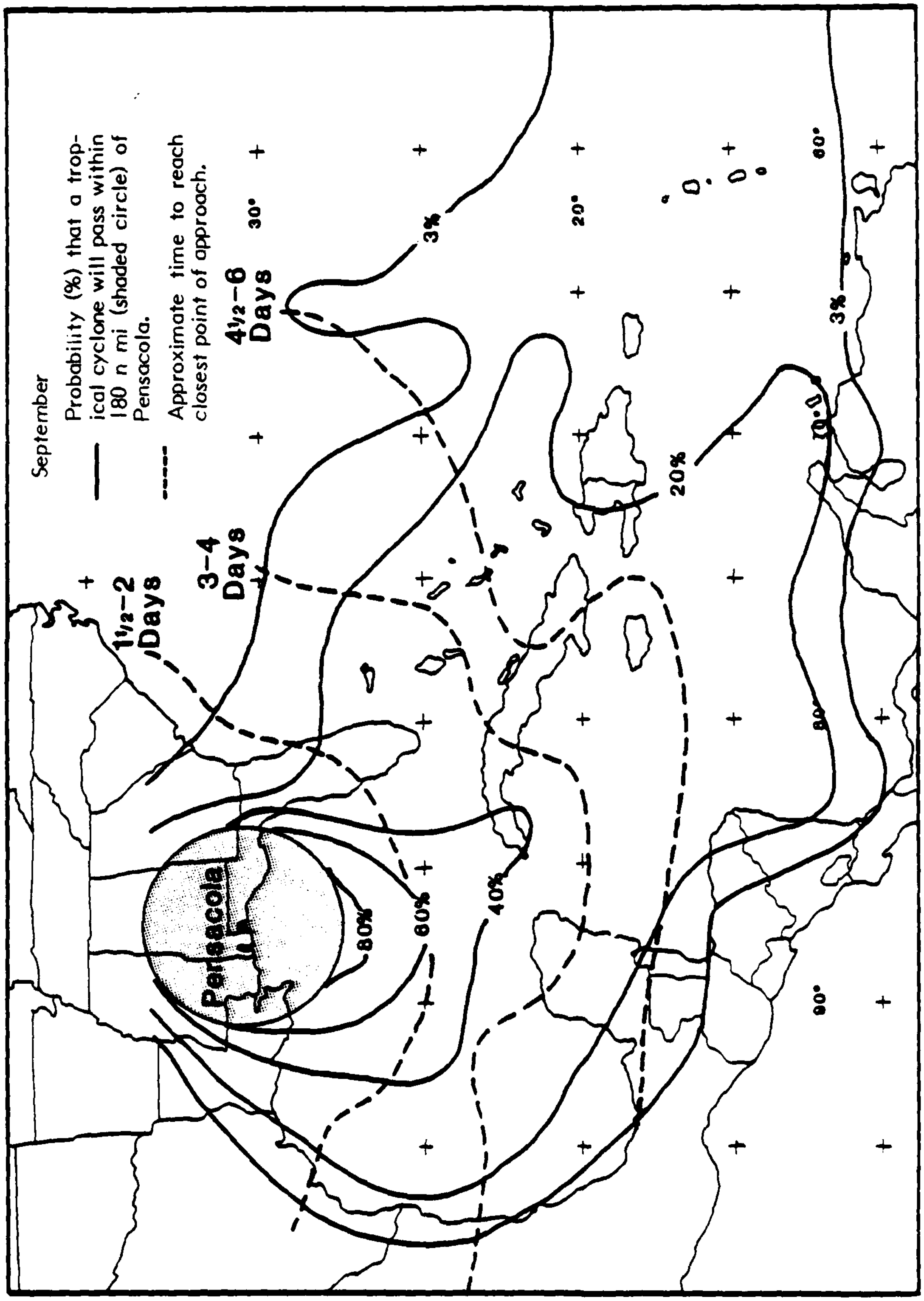


Figure X-9. Probability that a tropical cyclone will pass within 180 n mi of Pensacola during the month of September (based on data from 1871-1979).

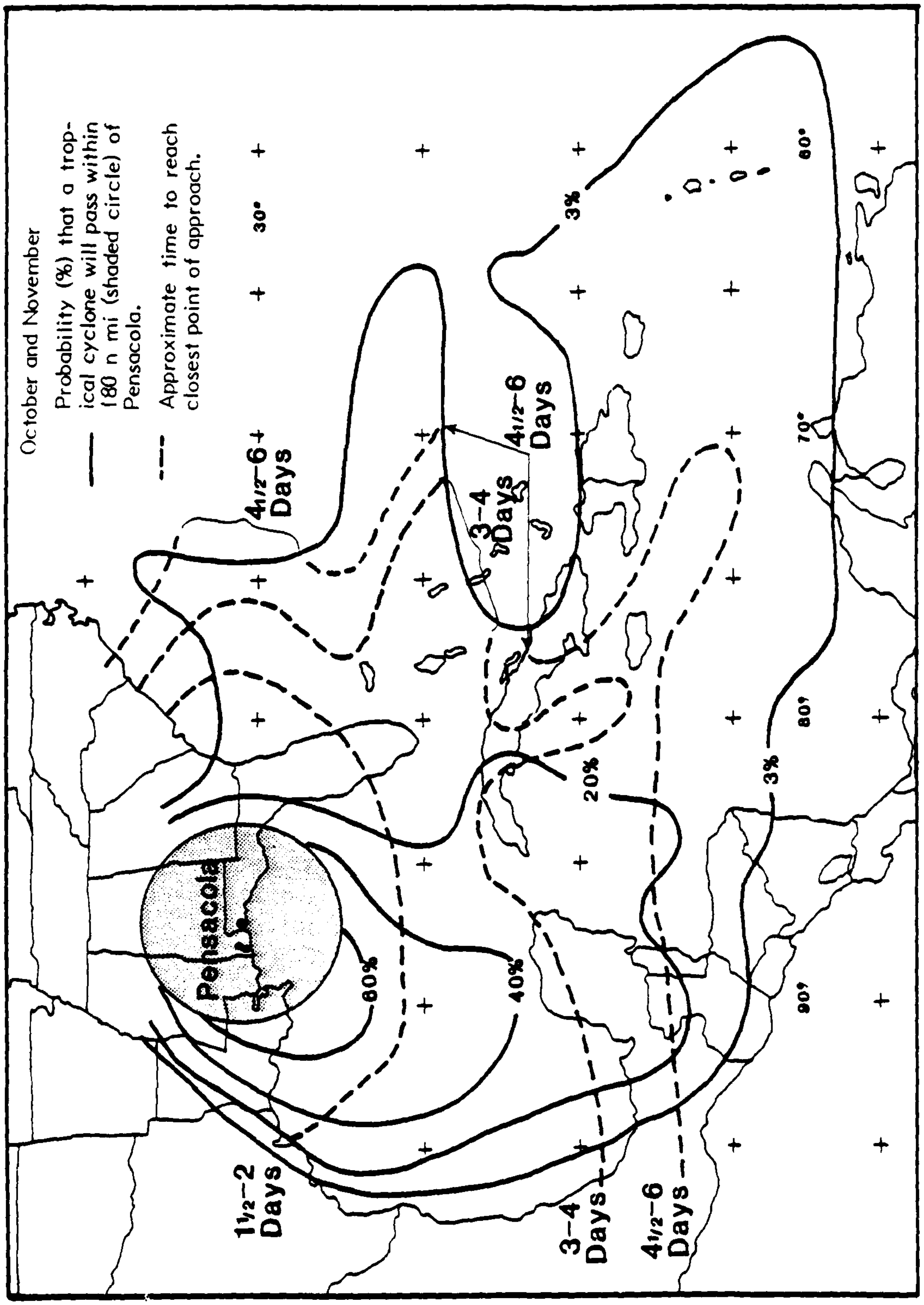


Figure X-10. Probability that a tropical cyclone will pass within 180 n mi of Pensacola during October and November (based on data from 1871-1979).

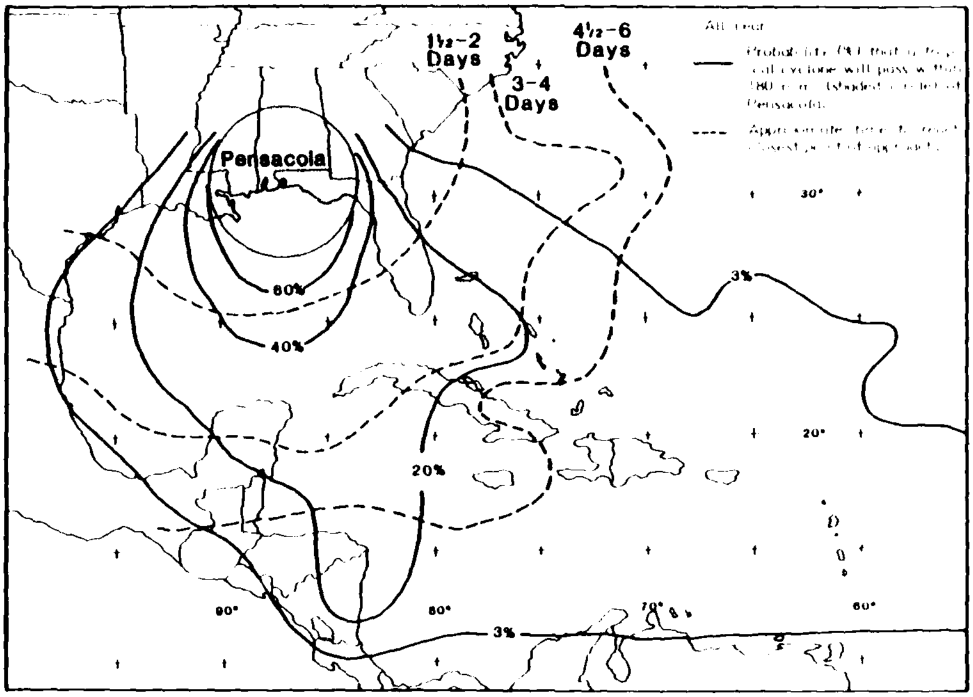


Figure X-11. Annual probability that a tropical cyclone will pass within 180 n mi of Pensacola (based on data from 1871-1979).

Since 1945, when routine aerial reconnaissance of tropical cyclones has provided more accurate position information, the average speed of advance for all tropical cyclones that have threatened Pensacola is 10 kt during June through September and 12 kt for those that approached in May and October.

A comparison of the figures suggests some distinct differences in the threat axis according to the time of year. Early in the season (May and June) the main threat to the Pensacola area is a track from just south of Jamaica across the western tip of Cuba to the south central gulf, then northward. A secondary threat axis passes westward across the Bahama Islands through the straits of Florida. A third axis begins in the western Caribbean and extends north joining the primary axis south of western Cuba.

As the season progresses into July and August (Figure X-8), the main threat axis shifts to the north following the northern coasts of the Greater Antilles through the Straits of Florida directly into the east central gulf coast. A secondary axis extends northward from the western Caribbean to join the main axis around Key West, Florida.

In September (Figure X-9) the main threat axis has shifted back southward closely resembling the main threat axis of May and June but maintaining evidence of a secondary axis through the Bahamas and developing a new threat axis from the western gulf.

Figure X-10 shows for the month of October the main threat axis extending from the Lesser Antilles through the central Caribbean, across the northern tip of Yucatan, recurving through the west central gulf to the U.S. central gulf coast.

Figure X-11 presents a composite picture of threat probability and time to CPA curves for the entire year and is derived from all tropical cyclone tracks passing within 180 n mi of Pensacola during the period 1871-1979.

3.3 WIND AND TOPOGRAPHICAL EFFECTS

In the 56-year period (1924-1979) for which wind data are available, 69 tropical cyclones approached within 180 n mi of Pensacola, an average of 1.2 per year. A tabular breakdown based on intensity of these cyclones while they were within 180 n mi of the port, is shown in Table X-1.

Table X-1. Classification of the 69 tropical cyclones which passed within 180 n mi of Pensacola between 1924 and 1979.

Hurricane (>63 kt)	Tropical Storm (34-63 kt)	Tropical Depression (<34 kt)	Total
22	39	8	69

Out of the 61 tropical storms and hurricanes, 16 caused sustained winds greater than 33 kt at Pensacola, based on hourly wind observations from 1924 to 1979. All 16 approached from the southwest, south or southeast. Seven of the 16 caused sustained winds of 50 kt or greater and nine of the 16 caused gusts reaching hurricane force. All that caused hurricane force winds at Pensacola formed outside the Gulf of Mexico. Most notable among these are the 1926 and 1929 hurricanes during which 96 kt winds were recorded and more recently during Hurricane Frederic when 83 kt wind gusts were recorded. Official hourly weather records since 1924 indicate that only the 1926 hurricane caused sustained hurricane force winds at Pensacola. Based on these historical records, gale force winds can be expected from one out of every 4 tropical storms/hurricanes passing within 180 n mi of Pensacola, and hurricane force winds from 1 out of every 7 tropical storms/hurricanes passing within 180 n mi of the port.

Figures X-12 through X-14 display the tracks of all 16 tropical cyclones (Neumann et al., 1978 and Hebert, 1980) producing winds greater than 33 kt in the period. Three figures are used simply to avoid clutter. Significantly, 11 of the 16 tropical cyclones occurred in the month of September, one occurred in early October, one in July, and three in late August. Also significant is the even distribution of approach directions to Pensacola; 5 approached from the southwest, 5 approached from the south, and 6 approached from the southeast.

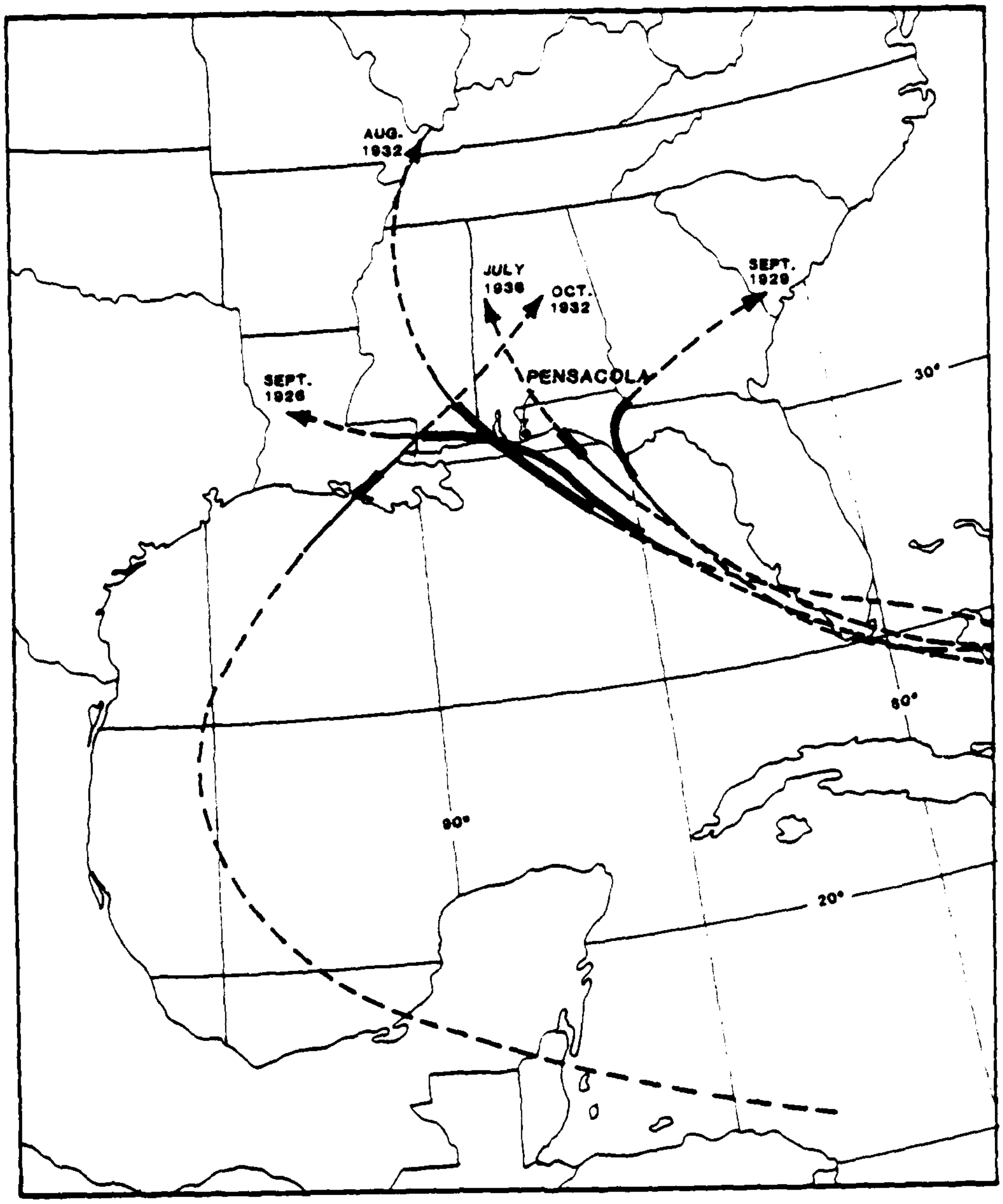


Figure X-12. Tropical cyclone tracks for the period 1924-1936 showing positions of tropical cyclone centers when winds greater than 22 kt (thin solid segment) and winds greater than 33 kt (broad solid segment) occurred at Pensacola. (Based on hourly wind data.)

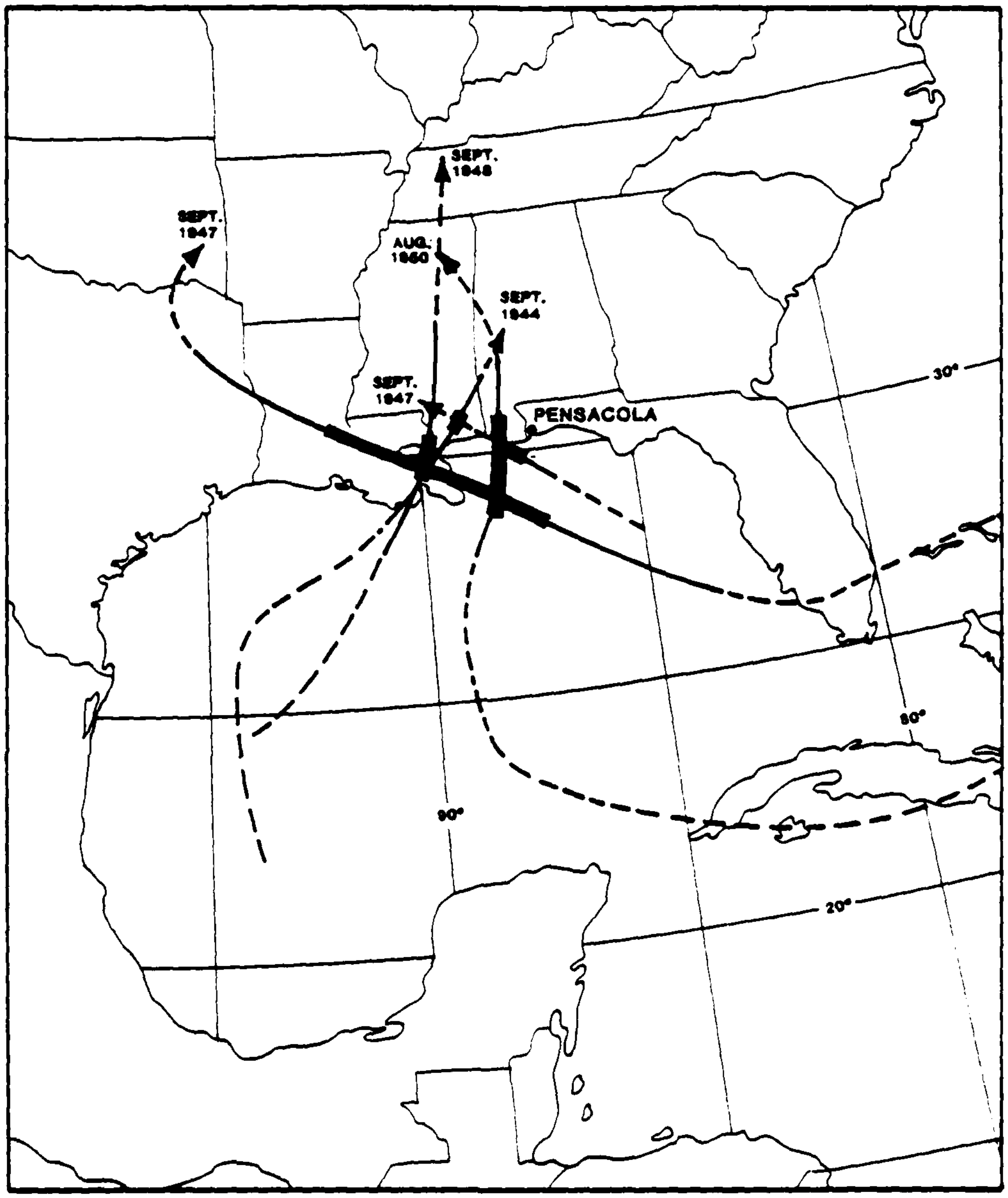


Figure X-13. Tropical cyclone tracks for the period 1937-1950 showing positions of tropical cyclone centers when winds greater than 22 kt (thin solid segment) and winds greater than 33 kt (broad solid segment) occurred at Pensacola. (Based on hourly wind data.)

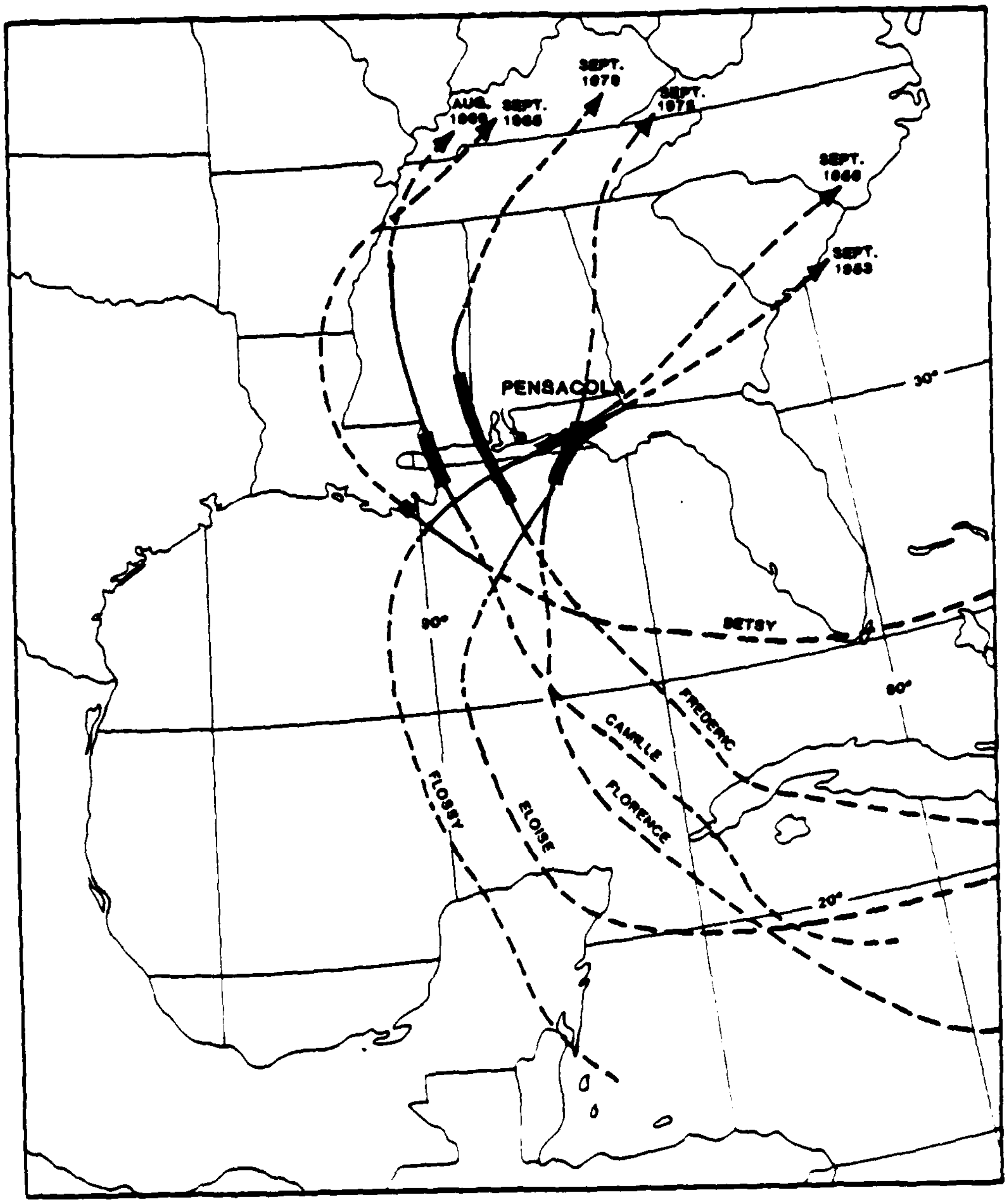


Figure X-14. Tropical cyclone tracks for the period 1951-1979 showing positions of tropical cyclone centers when winds greater than 22 kt (thin solid segment) and winds greater than 33 kt (broad solid segment) occurred at Pensacola. (Based on hourly wind data.)

The facilities of the Port of Pensacola are somewhat protected from northwest winds by the rising hills to the northwest (Figure X-1). NAS Pensacola receives this same protection from north-northeast winds. Limited protection from west and northwest winds is also afforded by frictional effects of the wooded landscape north and west of the bay.

The Port of Pensacola is particularly exposed to winds from the southeast, south, and southwest. The port facilities at NAS are vulnerable to all wind directions except those from the north-northeast.

Escambia and Blackwater Bays, oriented more or less north-south, pose a severe small boating hazard during periods of strong winds from these two compass points.

3.4 WAVE ACTION IN PENSACOLA BAY

Pensacola Bay is well protected from ocean wave activity by the sand barrier islands of Perdido Key and Santa Rosa Island. Only in cases of severe storm surge are these barriers breached so that ocean waves appear in the bay. High winds resulting from passing tropical systems do pose a serious wind wave problem at all deep water berths because of the large expanse of open water in the greater Pensacola Bay area which encompasses the East Bay, Blackwater Bay, Escambia Bay and Pensacola Bay Proper (see Figure X-1).

3.4.1 Pensacola Naval Air Station

The air station wharf and pier are particularly susceptible to high wind waves generated by easterly winds due to long over water trajectory (18 n mi on the axis 060°-240°) and deep water (over 20 ft) extending east-northeastward from the wharves some 9 miles into the bay. Sustained 35 kt east-northeast winds may produce wind waves 3 to 4 ft in height over the extreme western end of the bay. Similarly, 50 kt may produce 6 ft wind waves and 70 kt winds 7 ft wind waves at the Naval Air Station port facilities. Strong east and southeast winds can also cause wind waves of significant height. Sustained 35 kt winds from these directions may generate 3 ft waves; 50 kt winds, 4 ft waves; and 70 kt winds, 6 ft waves (U.S. Army Corps of Engineers, 1973).

The wharf and pier facilities are not affected to any great extent by wind waves generated by westerly or southerly winds.

3.4.2 Port of Pensacola

The Port of Pensacola located in the north shore of Pensacola Bay is most susceptible to wind waves resulting from strong winds from the east and southwest. Calculations indicate that a sustained 25 kt wind from these quadrants can produce 2 to 3 ft wind waves; 35 kt winds, 3 to 4 ft wind waves; 50 kt winds, 5 ft wind waves; and 70 kt winds, 6 to 7 ft wind waves (U.S. Army Corps of Engineers, 1973). High winds from the west through north do not produce significant wind waves affecting Port of Pensacola facilities.

3.5 STORM SURGE AND TIDES

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. This dome height is related to local pressure (i.e., intensity of the storm) and to the local winds. Other significant contributing factors are storm speed, direction of approach, bottom topography and coincidence with the astronomical tide.

The worst circumstances (Harris, 1963) would include the following:

1. Intense storm approaching perpendicular to the coast with landfall within 30 n mi to the west.
2. Broad, shallow, slowly shoaling bathymetry.
3. Coincidence with high astronomical tide.

Pensacola Bay readily fulfills these criteria -- particularly during August and September when the most intense tropical cyclones occur.

Two instances of strong storm surge which caused severe flooding and damage to Pensacola ports and facilities occurred during late September. The 1906 hurricane which made landfall 69 miles west of Pensacola with center winds of 110 kt resulted in a storm tide height of 10 ft. A storm tide of 9.7 ft occurred with the hurricane of September 1926, inflicting massive flood damage as the center passed just 16 miles southwest of NAS Pensacola. This hurricane approached from the southeast with 117 kt center winds on a direct path for Pensacola, decelerated to 6 kt, altered course, and moved inland 25 miles west of Pensacola Bay. Sustained winds at NAS exceeded 33 kt for 40 hours and exceeded hurricane force for 11 hours, mostly from the east and southeast. Much of the then Pensacola City and the Naval Air Station were under water.

Hurricane Frederic (September, 1979) moved ashore over Dauphin Island 55 miles west of Pensacola with maximum winds of 115 kt. High water resulting from storm tide reached 8 ft at Pensacola Bay entrance and 5 ft at the Port of Pensacola. Maximum high water of 15 ft occurred just west of Perdido Pass, 30 miles east of where the storm center made landfall. The storm tide associated

with Frederic exceeded 8 ft on a stretch of coastal area extending from 18 n mi west to 65 n mi east of where the storm center made landfall (U.S. Army Corps of Engineers, 1981).

The U.S. Army Corps of Engineers has developed tidal flood estimates for a hypothetical 100-year hurricane. Another calculated value known as Standard Project Tidal Flood has been calculated which represents the result from a hypothetical hurricane representing the most severe combination of parameters that reasonably can be expected excluding extremely rare combinations. These two values for various points in the Pensacola area are shown in Table X-2.

Table X-2. Combined effects of high astronomical tide and storm surge on high water levels associated with landfalling hurricanes approaching perpendicular to the Pensacola foreshore, i.e., a "worst case" simulation. Heights in the first column would occur once in 100 years on average and those in the second column can be described as the "worst conceivable." (Forecast Model Floods, U.S. Army Corps of Engineers, 1972.)

Location (see Figure X-1)	Intermediate Regional Tidal Flood (Feet Above MSL)	Standard Project Tidal Flood (Feet Above MSL)
Beach Front	11.0	12.7
Bay Entrance Fort Pickens to Bay Bridge	9.5	11.0
East Bay	9.0	10.5
Santa Rosa Sound (East of Bridge)	8.5	10.0
Escambia Bay at Highway 90	12.7	18.0
Blackwater Bay Bagdad & Milton	13.5	19.0

Flood tides reaching these calculated values would cover virtually all of the sand barrier island west of Pensacola as well as Santa Rosa Island south of the bay. A section of South Pensacola City including all water front terminal facilities and much of Pensacola NAS would be inundated. Accompanying wave action superimposed on such a flood tide would create extremely destructive conditions (U.S. Army Corps of Engineers, 1972).

There is little probability of severe storm surge activity from storms approaching from the east and west octants. Storms approaching from eastward are reduced in intensity by frictional affects of land along with north winds west of the center acting to move water away from the coast and bay. Storms

approaching from the west are similarly reduced in intensity and, with only part of the wind circulation over the Gulf, would not produce a severe storm surge threat.

Astronomical tides in Pensacola Bay range about 1.3 ft. Tidal currents within the bay are normally less than one knot. At the bay entrance diurnal tidal currents in mid-channel are about 2 kt (U.S. Dept. of Commerce, 1980). Currents of up to 11 kt at the entrance and 5 kt at the Naval Air Station pier have been reported. Current velocity would be greater during periods of heavy rainfall such as that associated with the passage of a tropical cyclone, and of course during a storm surge event.

4. THE DECISION TO EVADE OR REMAIN IN PORT

Instructions for hurricane preparedness at NAS Pensacola are addressed in NAS Pensacola OPLAN NR 3-(YR) and NAS Pensacola Air Operations Department Instruction 3140.7. The Captain of the Port of Pensacola uses the Hurricane Readiness Plan promulgated by the U.S. Coast Guard for guidance involving preparedness during hurricane threat situations. Definitions of Conditions of Alert are presented together with status of preparedness and action required or recommended to attain each condition of readiness.

4.1 THREAT ASSESSMENT

For the masters of deep draft vessels, the shortage of tug assistance and lack of protected along-side berths coupled with the elapsed time required to negotiate the ship channels leading to open water makes early assessment of an individual tropical cyclone threat essential. This assessment should be related to the setting of hurricane conditions of readiness by Navy, U.S. Coast Guard, and civil authorities and conducted using current advisories and forecasts issued by the Navy and National Weather Service, and climatology presented herein.

The greatest threat to Pensacola in terms of storm severity are tropical cyclones that have an origin outside the Gulf of Mexico and approach from the southwest, south or southeast with a forecast landfall within 100 n mi of the Port. A greater threat of storm surge occurs when tropical cyclones approach more or less perpendicular to the coast and make landfall within 75 n mi west and 40 n mi east of Pensacola. Of course the individual storm intensity and speed of movement affect the extent of damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Pensacola is located in the dangerous right front quadrant of the storm can result in severe wind and storm

surge conditions. The months of maximum threat in terms of frequency and severity are August and September.

A secondary threat comes from tropical cyclones approaching from the east and west or develop within 180 n mi of the port.

4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all deep draft vessels capable of making 15 kt or more when the port is under threat from an intense tropical cyclone approaching from the Gulf of Mexico and which threatens to landfall within 100 n mi of the port.

Timing of this decision is affected by:

1. The forward speed of the tropical cyclone.
2. The radius of hazardous winds and seas that can impact on a vessel's capability to reach open water and then maneuver to evade.
3. The elapsed time to make preparation to get underway.
4. The elapsed time to reach open water.

For example: The worst case situation would be an intense tropical cyclone moving more or less directly toward Pensacola from the south. Assume 6 hours are required to make preparations for leaving port after the decision to evade at sea is made, and assume another 4 hours are required to transit the channels enroute to the open sea. A tropical cyclone approaching at an average speed of 10 kt will have moved 100 miles closer to Pensacola by the time open water is reached. Add to this the radius from the tropical storm center of strong winds likely to hamper harbor operations, say 200 n mi. Summing these values gives 300 miles (200 + 100) or 30 hours as the minimum tropical cyclone displacement from Pensacola in distance or time when the decision must be made to evade at sea successfully. A greater margin may be applicable depending on greater cyclone speed and intensity.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. It is apparent that the decision to prepare for sortie should be made soon after setting Hurrican Condition III. Although at this time the storm center may be more than 500 miles distant, it should be remembered that the average forecast error over a 48-hour period is on the order of 244 miles.

The aircraft carrier LEXINGTON, and the destroyer OWENS, both home ported at NAS Pensacola, make for the open sea once Hurricane Condition of Readiness III (hurricane force winds expected in 48 hours) is set. This is considered to be the wise and safest course of action. Later departures than this wager the accuracy of information on the storm's behavior against mounting risks of heavy weather damage.

Once sea room is attained on departure from Pensacola, the tactics employed will depend, of course, on the location of the threatening tropical storm, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information with today's satellite technology is highly accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity and movement.

Ship masters with access to these advisories/warnings are in the best possible position to modify evasive routes and tactics, as required, to successfully evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered:

1. Tropical cyclones approaching from the east or southeast:

   Steam southwest to increase distance from the storm taking advantage of the northerly winds and seas.

2. Tropical cyclones approaching from the southwest and west.

   After an early departure to escape worst effects of head winds and seas, steam south or south-southeast to reach a latitude south of storm center.

3. Tropical cyclones approaching from the south:

   Tropical cyclones moving through the Gulf of Mexico in this quadrant present the most vexing of evasion problems. In August and September many storms move north directly into the the coast. In October there is a strong likelihood of cyclone recurvature to the northeast while still centered over the Gulf. An evasion route decided on earlier may have to be altered based on unexpected changes in cyclone movement. Evasion tactics must be based on the latest tropical cyclaone forecast position and movement.

4.3 RETURNING TO HARBOR

The damage and disarray at a port resulting from a tropical storm strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with Port Authorities before attempting to return.

4.4 ASSUMING A "WAIT AND SEE" POSTURE AT ANCHOR

A marginal threat may dictate a "wait and see" posture at anchor in the bay as the most sensible course of action to follow. A marginal threat involves those situations where an intense tropical storm or hurricane is a considerable distance away and not likely to cause severe conditions at Pensacola within 48 hours, or situations where the storm system is meandering in the gulf with no

established direction of movement. Leaving the pier for anchorage in the bay to await later developments in storm intensity and/or movement offers the advantage of decreasing the time to reach the open sea should evasion become necessary.

4.5 REMAINING AT PENSACOLA

Remaining at Pensacola is an option that should receive serious consideration under the secondary threat situation and in those instances when a vessel is incapable of successful evasion at sea.

The secondary threat situation includes the following:

1. A tropical cyclone developing within the 180 n mi radius critical area.
2. A weak tropical cyclone approaching from the gulf.
3. A tropical cyclone approaching overland from the east or west
4. A tropical storm/hurricane expected to approach within 180 n mi and make landfall more than 100 nmi from the port.

If the decision is to remain in Pensacola, an anchorage in the bay is the recommended course of action. Riding out a severe storm alongside at the Naval Air Station or at the Port of Pensacola is extremely hazardous due to exposure to high winds and waves.

Good anchorage can be found in any part of the bay except south of the Naval Air Station (U.S. Coast Pilot 5, 1980). Anchoring in the Safety Fairway is not normally permitted according to Coast Guard authorities. A freighter is reported to have used the anchorage off the Port of Pensacola (position marked "A" in Figure X-2) without great difficulty during the passage of Hurricane Frederick in 1979.

Riding out the storm at anchor east of the Bay Bridge is not recommended since damage to this fixed bridge could effectively imprison a vessel for many days.

A similar hazard may exist regarding shoaling in the bay entrance resulting from abnormal waves or currents. According to local authorities, however, significant shoaling in the bay entrance has not occurred in living memory.

5. ADVICE TO SHALLOW DRAFT VESSELS

Shallow draft vessels should, if feasible, be removed from the water and firmly secured ashore at an elevation above 20 ft to avoid possible high water. Short of this, seek shelter in one of the bayous or the upper reaches of Blackwater River below the city of Milton. Keep in mind that southerly winds and storm surge associated with a tropical cyclone approaching from the gulf and making landfall west of Pensacola, or passing close to Pensacola, may cause heavy flooding.

Possible sheltered water locations are summarized as follows (see Figure X-1):

1. Bayou Grande. Offers limited wind protection and is vulnerable to high water levels caused by strong easterly winds.

2. Bayou Chico. Good north wind shelter. Poor shelter from east winds. Busy with marine industrial activity. Subject to extreme shoreside flooding.

3. Bayou Texar. Avoid the lower reaches of Bayou Texar when strong southerly winds are expected, otherwise considerable wind protection is afforded.

4. Santa Rosa Sound and Big Lagoon. Both bodies of water should be avoided as a shelter. Little or no wind protection is afforded here and both are extremely susceptible to storm surge effects and the intrusion of gulf water by waves over-running the sand barrier of Santa Rosa Island and Perdido Key. Using the intracoastal waterway for an exit to the west and Perdido Bay may be a suitable course of action to avoid the effects of tropical cyclones moving over the gulf well to the ·t of Pensacola.

5. East Bay River. Vulnerable to high water buildup caused by west winds and storm surge in the bays, otherwise some wind protection.

6. Escambia and Blackwater Rivers. Little wind protection. Susceptible to high flood water caused by strong southerly winds and storm surge effects.

7. Anchoring or Mooring Practices:

   a. Anchor out in a bayou, slew or river with plenty of swinging room. Use two anchors forward.

   b. Moor close into shore between the banks of rivers, creeks, and streams. Use bow and stern lines fastened to lower tree branches.

   c. The following extract from the U.S. Coast Pilot 5 (1980), Gulf of Mexico, Puerto Rico, and Virgin Islands -- is relevant:

   > "Hurricane moorings. On receiving advisory notice of a tropical disturbance small boats should seek shelter in a small winding stream whose banks are lined with trees, preferably cedar or mangrove. Moor with bow and stern lines fastened to the lower branches; if possible snug up with good chafing gear. The knees of the trees will act as fenders and the branches, having more give than the trunks, will ease the shocks of the heavy gusts. If the banks are lined only with small trees or large shrubs, use clumps of them within each hawser loop. Keep clear of any tall pines as they generally have shallow roots and are more apt to be blown down."

Seeking shelter at berthing facilities along the shores of Pensacola Bay proper is not recommended for any tropical cyclone threat that could cause strong winds in the bay with an easterly or southerly component, i.e., cyclone approaching from the gulf or from the west passing close to Pensacola to the north or south.

Using open bay anchorages to ride out the passage of a tropical cyclone is extremely hazardous. Virtually no wind protection is afforded except off the north shore against north or northwest winds. Wind wave activity can be quite destructive, not to mention the hazards of floating debris resulting from the effects of wind wave, high water and high winds.

The prudent small boat operator will have selected several potential "holes" beforehand in which to take shelter in various tropical cyclone threat situations. He will proceed to his "hole" well in advance to avoid the chaos and congestion enjoyed by his fellow boat owners who delay until the onset of destructive conditions is imminent.

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XI: CONTENTS

XI. GULFPORT, MISSISSIPPI

SUMMARY

History has demonstrated that the hurricane season represents a serious threat to marine activities at Gulfport. The Mississippi coast has been affected by tropical cyclone activity at an average frequency of 1.2 per year. Since 1942 there have been 8 tropical cyclones which produced sustained 50 kt winds or greater at Gulfport. During this century there have been five occurrences of tropical cyclone storm tides exceeding 8 ft along this section of the Mississippi coast, the most recent being a storm tide of 21 ft at Gulfport which accompanied Hurricane Camille in 1969.

The hurricane season is late May through early November. September is by far the major threat month. The principal threat to Gulfport is from tropical cyclones approaching from the southwest, south and southeast. Eighty-three percent of all tropical cyclones entering the 180 n mi critical area in the 109-year period between 1871-1979 approached from these sectors.

Gulfport Harbor is not a hurricane haven. Evasion rationale is based on the harbor's location in the hurricane belt, the absence of sheltered facilities and anchorages for deep draft vessels, and the danger of severe shoaling in the narrow Gulfport channel caused by passing tropical cyclones. Early threat assessment is essential due to the elapsed time required to reach open water and the limited number of evasion routes available after reaching the Gulf of Mexico. Deep draft vessels should ride out the threat at anchor in the shallow waters adjacent to the sand barrier islands some 10 miles off shore in certain secondary threat situations or if unable to sortie.

Advice for shallow draft vessels is to remove the craft from the water. Otherwise, seek shelter in the Back Bay of Biloxi and the creeks, bayous and rivers leading inland.

1. GEOGRAPHIC LOCATION AND TOPOGRAPHY

As shown in Figure XI-1, the port of Gulfport, Mississippi is located on Mississippi Sound 60 miles west of Mobile Bay about midway between Biloxi Bay and St. Louis Bay. Mississippi Sound is an open sound which stretches westward from Grants Pass near Mobile Bay. Ship and Cat Islands, two low lying barrier islands separating Mississippi Sound from the Gulf of Mexico, lie 10 miles offshore from Gulfport.

This hurricane haven evaluation was prepared by R.E. Wrenn of Ocean Data Systems, Inc. (ODSI), Monterey, CA 93940.

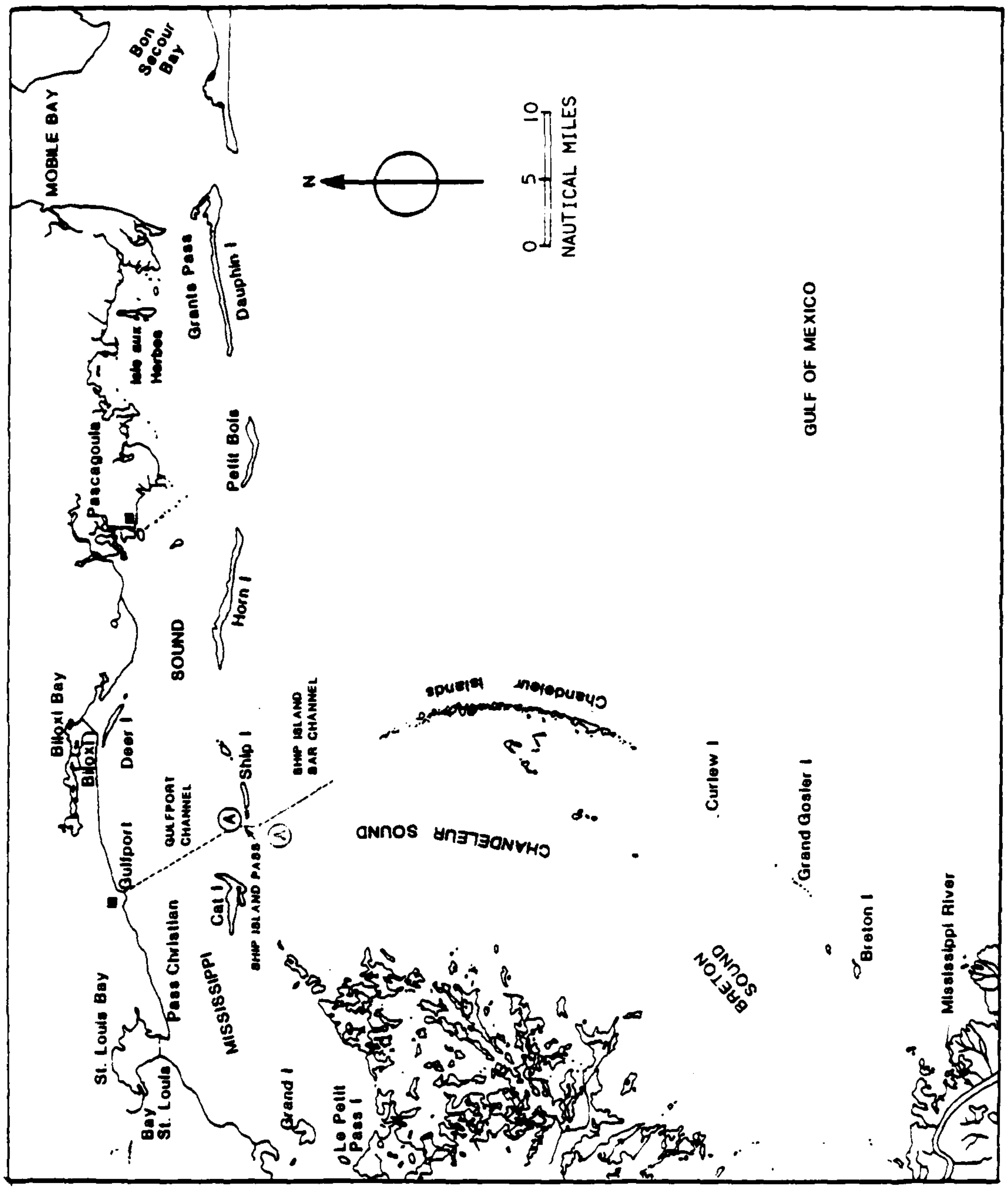


Figure XI-1. Mississippi Sound showing approach channel to Gulfport, with offshore anchorages designated by a circled A.

Bottom topography in the sound is gently sloping from 18 ft just inside the barrier islands to the mainland beaches. The mainland terrain is generally low and flat rising off the beach to an elevation of 25 ft 1000 to 2000 ft inland, lowering to near sea level at Bernard Bayou and Gulfport Lake 3 miles north of the city (Figure XI-2), then sloping gently to 50 ft some 7 to 10 miles inland from the gulf.

2. PORT AND HARBOR FACILITIES

2.1 HARBOR FACILITIES FOR DEEP DRAFT VESSELS

Gulfport's main harbor (Figure XI-3) consists of an artificially constructed rectangular basin formed by two parallel piers 1320 ft apart extending some 3400 ft into Mississippi Sound. Basin project depth is 30 ft. See Nautical Chart 11372 for controlling depths. Berths for deep draft vessels are inside the harbor along East Pier which has 1440 ft of berthing space including the Banana Terminal, and West Pier which has 3500 ft of berthing space. Deep draft berths are numbered 3 through 5 and 8 through 10. Transit sheds, warehouses and open storage areas occupy a large portion of both piers. Deck heights are 10 and 11 ft. A more complete treatment of port facilities for deep draft vessels may be found in Port Series 19 published in 1979 by the U.S. Army Corps of Engineers.

Access to the port is via Ship Island Bar Channel which is 6 miles in length and leads from the Gulf of Mexico to Ship Island Pass, and Gulfport Channel (Figure XI-1) which is 11 miles in length and leads through Mississippi Sound to the harbor entrance. Project dimensions for Bar Channel is 300 ft wide with a depth of 32 ft. Project dimensions for Gulfport Channel is 220 ft wide with a depth of 30 ft. The total distance from harbor entrance to open water at the 100 fathom curve is approximately 100 miles. Speed in Gulfport Channel for ocean-going vessels is limited to 8 kt (U.S. Coast Pilot 5, 1980).

Two tugs, one 1200 horsepower and the other 800 horsepower, operated by the Gulfport Towing Company, are available to perform docking, undocking and shifting services in Gulfport Harbor. Requirements for tug services must be made in advance. Vessels usually enter and leave the harbor under their own power.

Gulfport has no shipyard facilities. Major repair facilities including drydocking facilities are available at nearby Pascagoula, Mississippi (Figure XI-1).

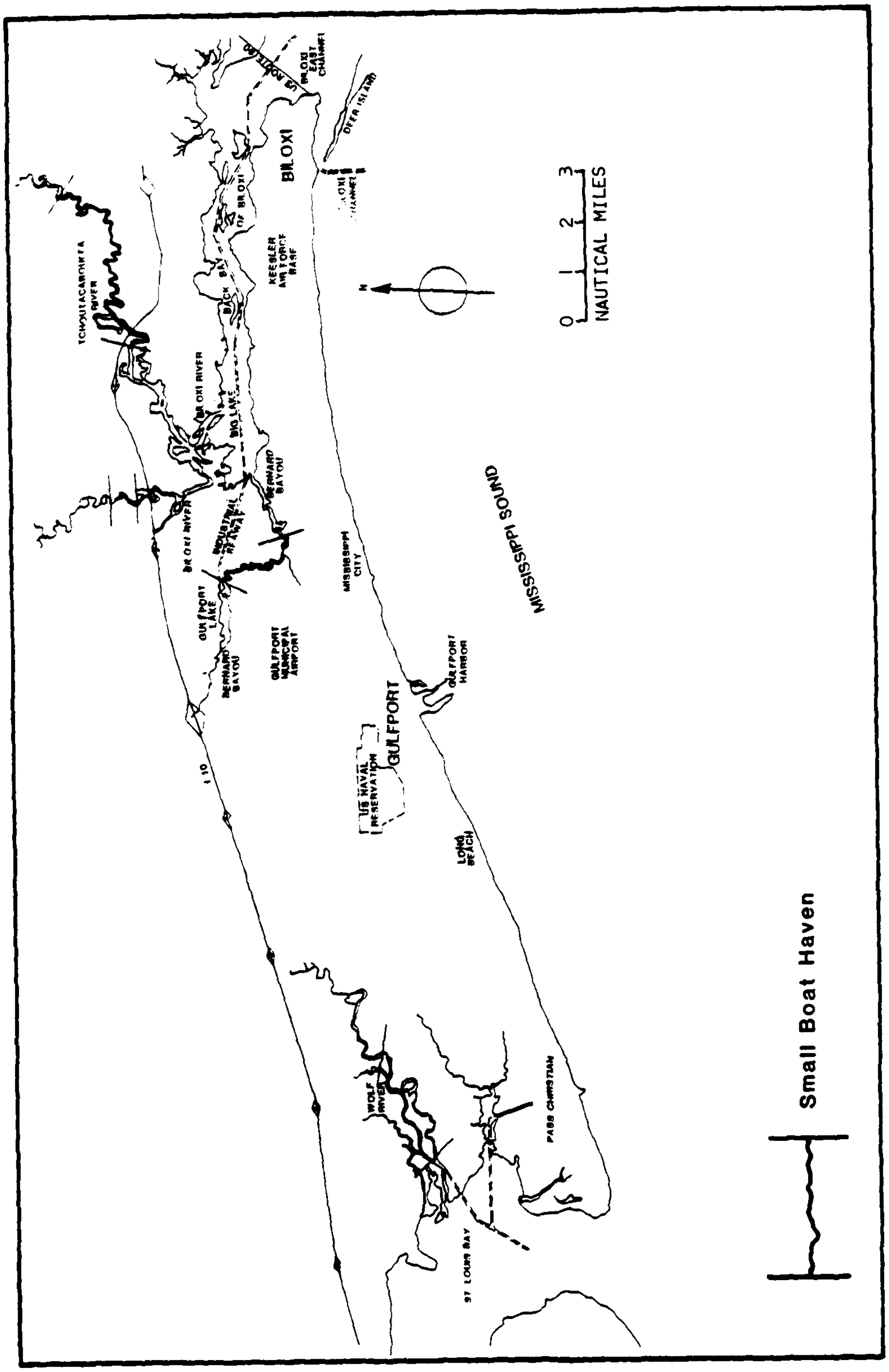


Figure XI-2. Small boat havens in the Gulfport area.

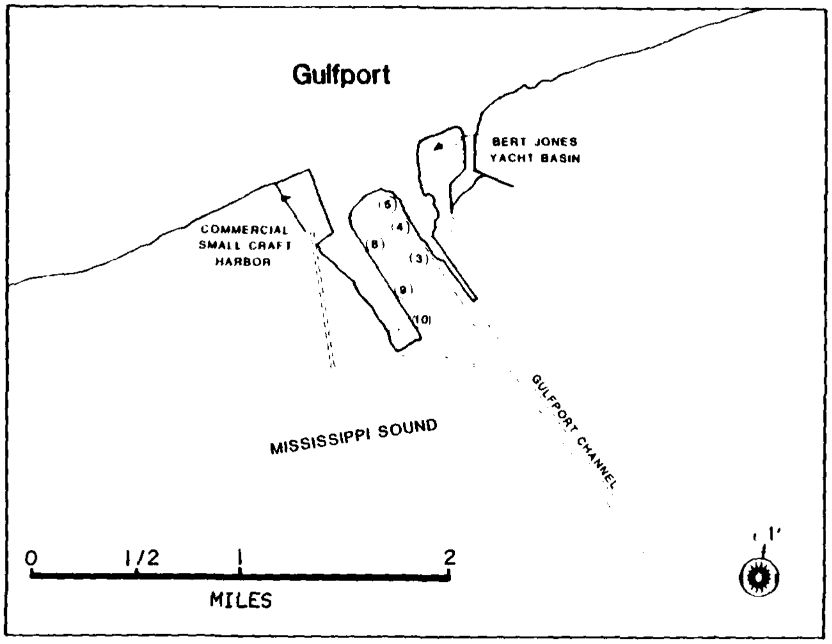


Figure XI-3. Gulfport Harbor.

2.2 HEAVY WEATHER FACILITIES AND ANCHORAGES

Gulfport Harbor offers little in the way of shelter from heavy weather. Buildings on the piers and the wooded landscape offer some wind protection from north, west and east winds. The harbor is exposed to winds from the southwest, south, and southeast.

Anchorages for large vessels include the waters west of a line between Chandeleur and Ship Island lights just south of the bar where holding ground is good (U.S. Coast Pilot 5, 1980). Bar pilots report good anchorage 0.5 miles south of Ship Island Pass Light Bell Buoy 26. Ship Island Harbor just north of Ship Island can accommodate vessels with drafts up to 20 ft but there is swinging room for only one vessel. Ship Island shelters the anchorage from southerly winds and seas. Cat Island serves to shelter the anchorage to some extent from west winds. These anchorages are marked with the letter "A" in Figure XI-1.

2.3 FACILITIES FOR IN-SHORE VESSELS

The Bert Jones Yacht Basin, shown in Figure XI-3, located immediately east of the main harbor has facilities for pleasure craft and commercial vessels. Berths, fuel and marine supplies are available. Hull and engine repairs can be performed. The Yacht Basin is roughly 1500 by 1200 ft and formed by an earth

fill pier and breakwater. The basin controlling depth is reported to be 7 ft and is privately maintained. Access is via a narrow channel with a reported depth of 8 ft.

The commercial Small Craft Harbor located immediately west of the main harbor and adjacent to the West Pier at the inner end is used for small commercial vessels and barges. This basin is formed by a concrete sheet pile breakwater on the west side and concrete bulkheads on the north and east sides. Piers and wharfs accommodate commercial tenant fishing craft and fuel barges. Deck heights are 6 ft. Controlling depth of the basin is 8 ft. Normal water depth at the entrance is 3 ft. Access to the basin is via a narrow hannel which extends from Gulfport Channel.

Other small craft facilities, both private and public may be found at Ocean Springs and Biloxi to the east and in the Back Bay of Biloxi (see Chart 11372 and Figure XI-2). Repair facilities are also available in Gulfport Lake on the Industrial Seaway which is reached via Back Bay of Biloxi and Big Lake.

Access to Biloxi, Ocean Springs and Back Bay is via Biloxi East Channel, east of Deer Island, and Biloxi Channel (Figure XI-2) which passes west of Deer Island. Controlling depths are 9 and 7 ft respectively. Access to Back Bay is via a channel between Plummer Point and Biloxi past the U.S. Route 90 highway bascule bridge.

Small craft anchorages offering good heavy weather protection from all directions are excellent in the Back Bay of Biloxi where depths are 5 to 15 ft and the bottom is soft (U.S. Coast Pilot 5, 1980). Shallower draft craft can find good protection upstream in Biloxi and Tchoutacabouffa Rivers and in Bernard Bayou (Figure XI-2).

3. ANALYSIS OF THE TROPICAL CYCLONE THREAT AT GULFPORT

3.1 INTRODUCTION

By examining relevant characteristics of tropical cyclones such as track, speed of movement, intensity, month of occurrence, etc., some insight may be gained into their typical behavior. This background knowledge and understanding allows attention to be focused on those storms most likely to have a serious effect on Gulfport. However, the historical behavior of storms and their impact should not be regarded as a reliable guide to the detailed behavior and impact of a particular storm as it approaches the port.

3.2 CLIMATOLOGY

For the purpose of this study, any tropical cyclone approaching within 180 n mi of Gulfport is considered to represent a threat to the port.

The outstanding feature of the U.S. gulf coast region is its location on the north shore of the Gulf of Mexico and its orientation perpendicular to normal tropical cyclone tracks as they move more or less northward out of the tropics. Also important is the regions position between 25 and 30 degrees north latitude which is within the normal locus of tropical cyclone recurvature which oscillates between latitudes 25N and 35N during the tropical cyclone season. This latter factor is significant since it is the character of tropical cyclones to slow and intensify during the recurvature stage. During this phase of the tropical cyclone life cycle, it is difficult to predict with great accuracy the rate of recurvature, the storm speed of movement subsequent to recurvature, and obviously, the storm's precise future position at a point in time.

The "Hurricane Season" along the gulf coast is late May through early November. During the 109-year period between 1871 and 1979 there were 128 tropical cyclones which met the 180 n mi threat criteria for Gulfport, an average of 1.2 per year. The following table shows the monthly totals and percentages. These data are graphically presented in Figure XI-4.

Month	Number	% of Total
May	1	0.7
June	12	9.3
July	15	11.7
August	18	14.0
September	58	45.3
October	23	18.0
November	1	0.7

It is apparent that the frequency of the tropical cyclone threat for Gulfport increases gradually through June, July and August reaching a peak in September, then falling off in October. Such threats are rare in May and November. The greatest number of tropical cyclones affecting Gulfport have occurred during the latter half of September.

Figure XI-5 illustrates 125 events during the 109-year period as a function of compass octant from which tropical cyclones have approached Gulfport[1]. The numbers in parentheses represent the percentage of cyclones from the sample

[1] Three tropical cyclones developed within 180 n mi of Gulfport and were at their closest points of approach at the time of formation. An approach direction is therefore not applicable to these three.

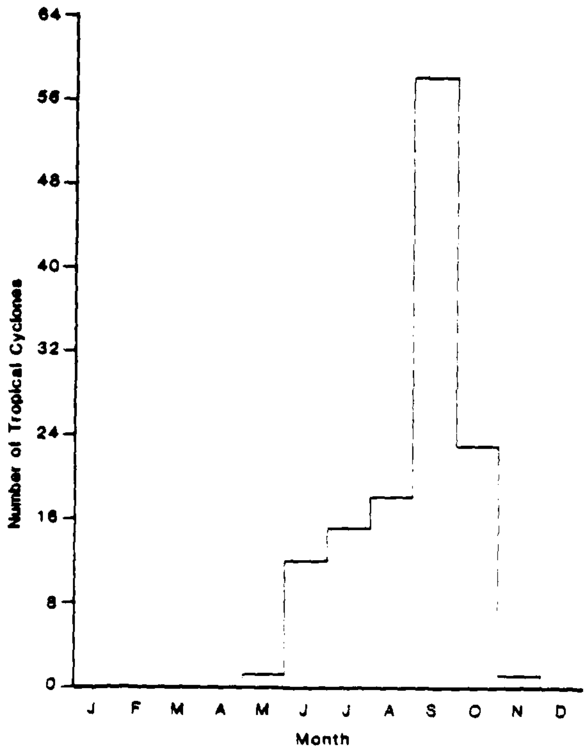
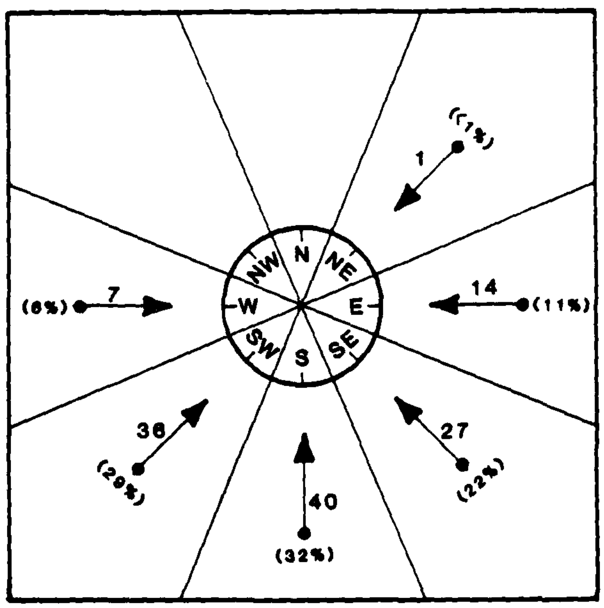


Figure XI-4. Frequency distribution of tropical cyclones that passed within 180 n mi of Gulfport during the period May-November (based on data from 1871-1979).

Figure XI-5. Direction of approach of tropical cyclones that passed within 180 n mi of Gulfport (based on data from 1871-1979). Numerals show the number of storms approaching from each octant; percentages in () are percent of total sample from each octant.



approaching from a particular octant. The figure shows that the predominant threat sector extends from the southwest through the southeast from which a full 83% of the tropical cyclones affecting Gulfport have approached. The largest percentage (32%) have approached from the south.

It is significant to note that a small number of tropical cyclones have developed within a 180 n mi radius of Gulfport. One developed quickly to hurricane intensity while in the threat area.

Records of tropical cyclones passing through the 180 n mi critical area during the 80-year period 1900-1979 for which cyclone intensity data are available are tabulated in Table XI-1 by intensity and month of occurrence. Of the 95 such occurrences it can again be seen that September is by far the principal threat month in terms of numbers of tropical cyclones affecting Gulfport but the higher monthly percentage of the more dangerous class of storm is in October-November (12 out of 15). July on the other hand, is nearly equal to May-June, August and October-November in number of occurrences but has a much lower percentage of occurrence for violent tropical cyclones. Overall, 56 out of 95 tropical cyclones (58%) affecting Gulfport in this century were in the strong category.

Table XI-1. Classification of 95 tropical cyclones which passed within 180 n mi of Gulfport during the 1900-1979 period.

Maximum Intensity*	May June	July	Aug	Sep	Oct Nov	Totals
Hurricane	1	3	8	21	4	37
Intense Tropical Storm	6	1	1	3	8	19
Weak Tropical Storm	3	5	3	16	2	29
Tropical Depression	1	3	0	5	1	10
Totals	11	12	12	45	15	95

*Intensity values reflect the maximum intensity while in the final phase of the tropical cyclone's approach to the port.

Figures XI-6 through XI-10 are statistical summaries of threat probability for the years 1871 to 1979. These summary data are presented in five charts, each representing data encompassing specific periods during the year. These periods are:

Tropical cyclones occurring during May and June.
Tropical cyclones occurring during July and August.
Tropical cyclones occurring in September.
Tropical cyclones occurring during October and November.
All tropical cyclones of record during the 109-year period.

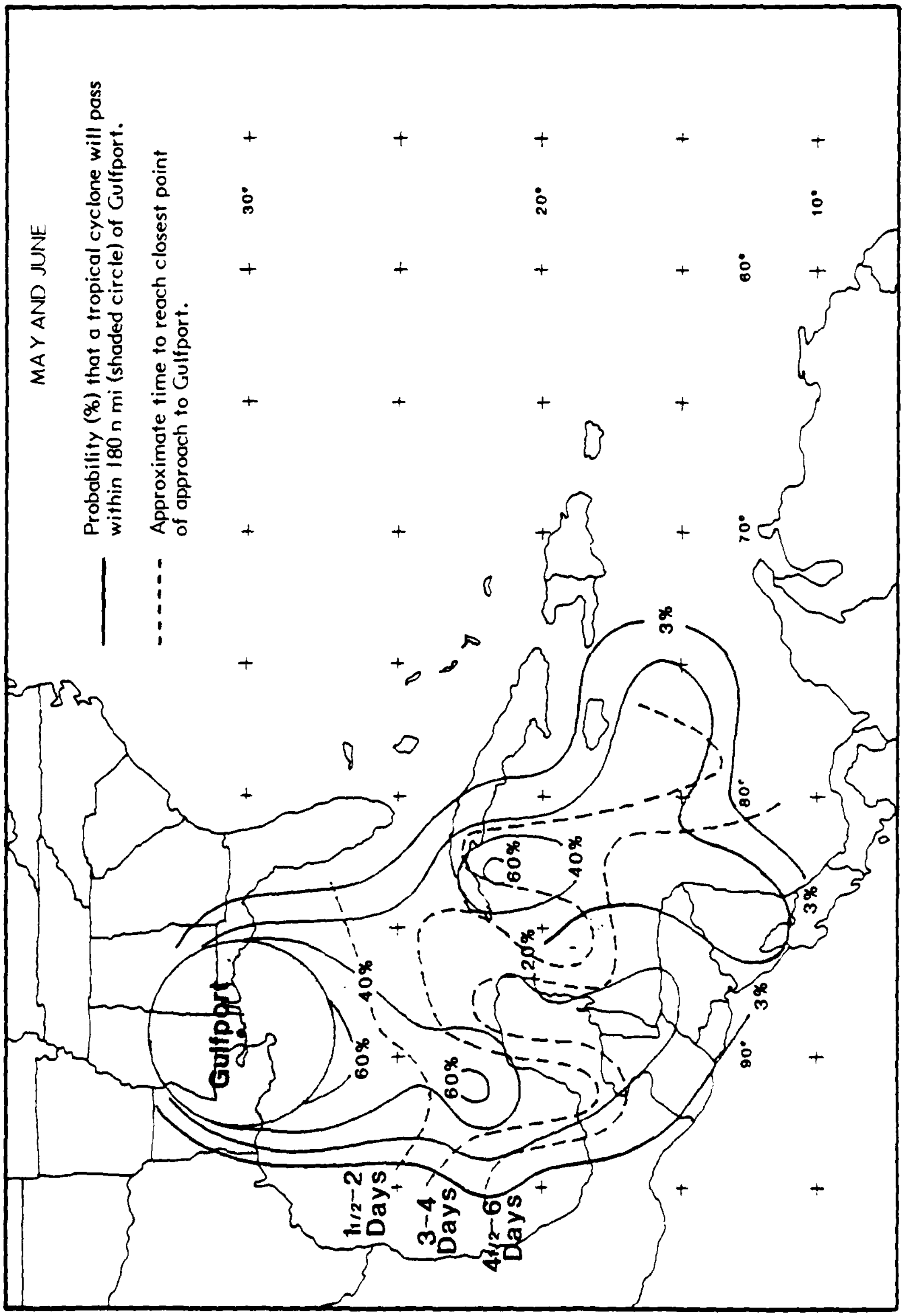


Figure XI-6. Probability that a tropical cyclone will pass within 180 n mi of Gulfport during the months of May and June (based on data from 1871-1979).

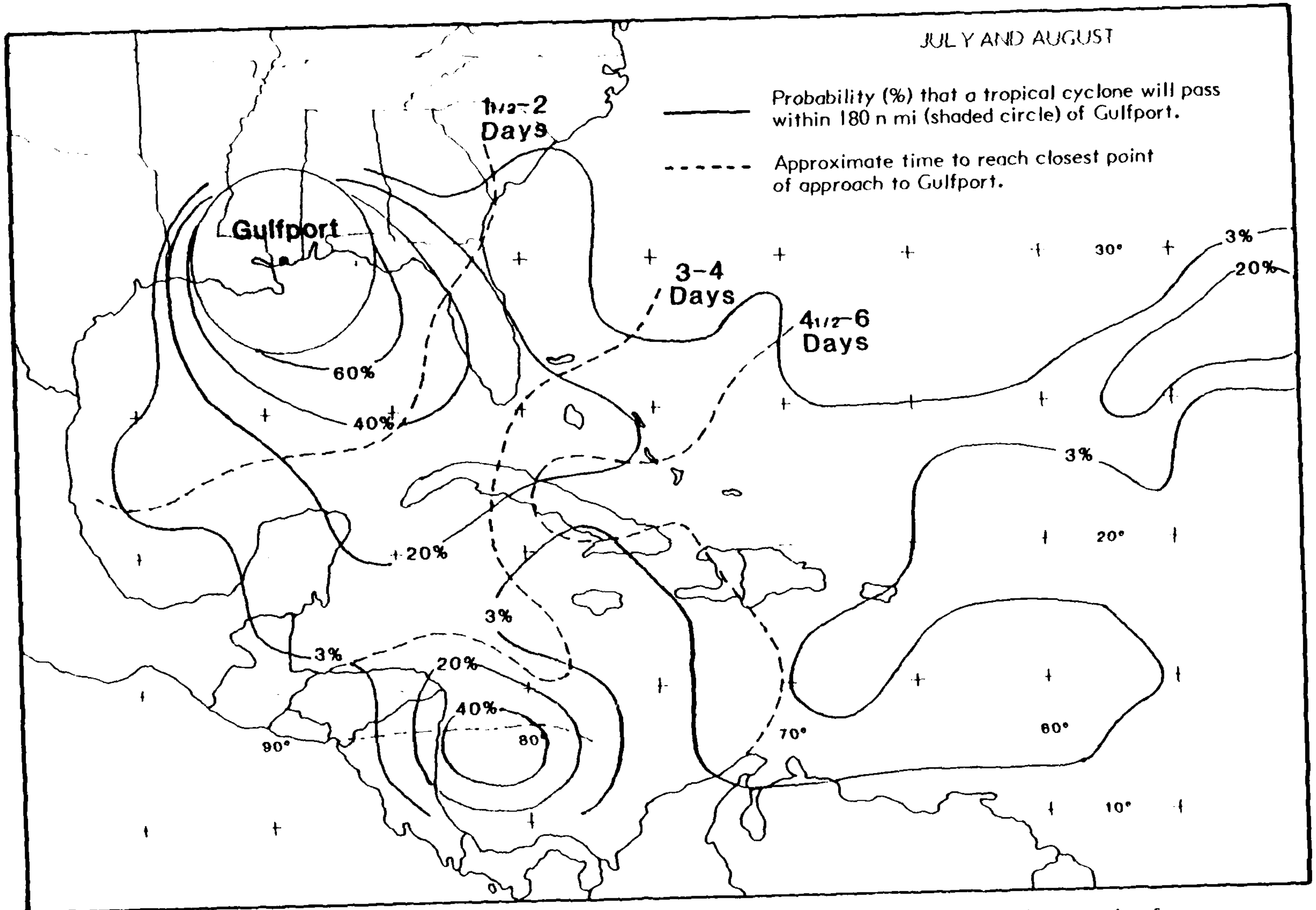


Figure XI-7. Probability that a tropical cyclone will pass within 180 n mi of Gulfport during the months of July and August (based on data from 1871-1979).

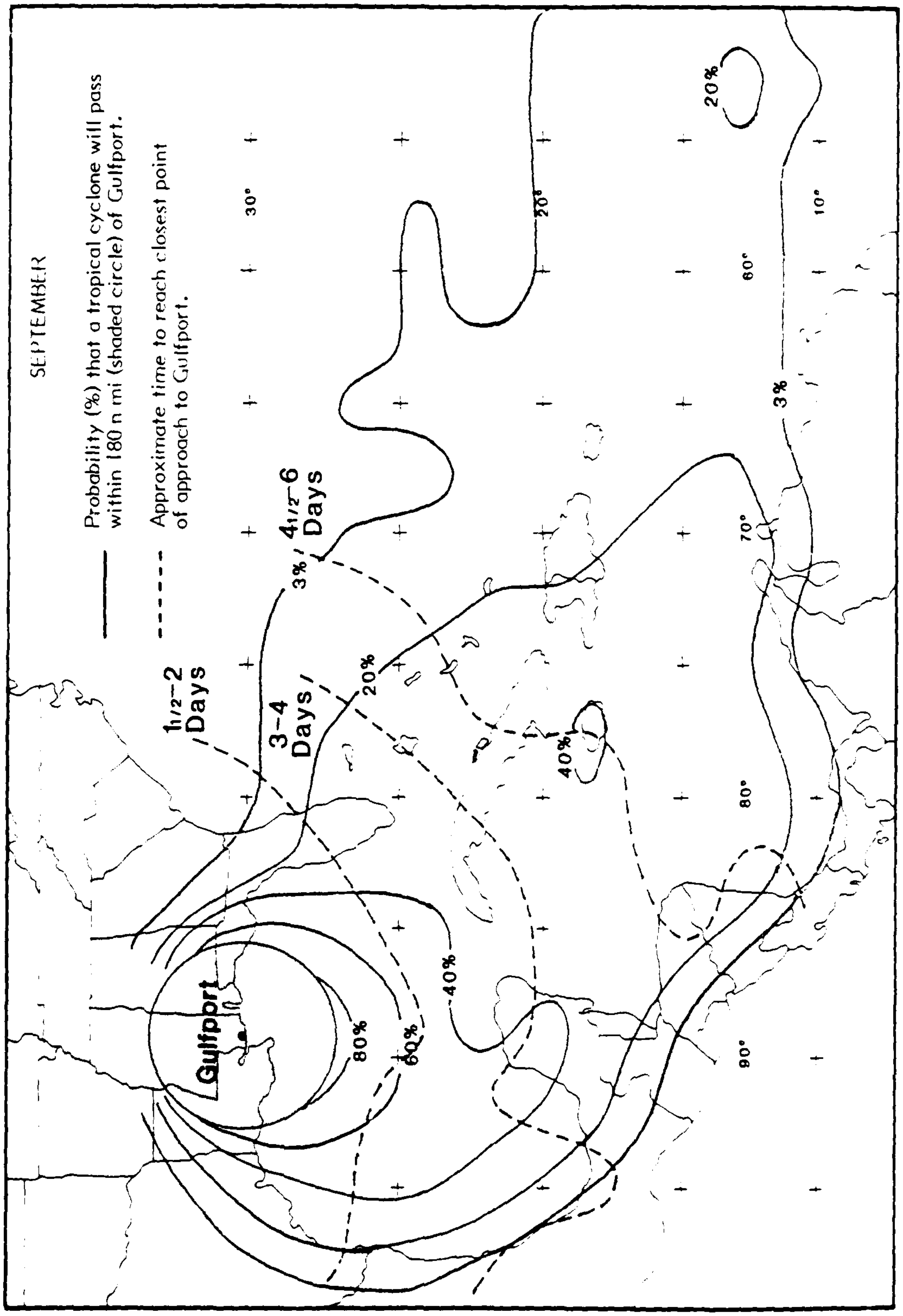


Figure XI-8. Probability that a tropical cyclone will pass within 180 n mi of Gulfport during the month of September (based on data from 1871-1979).

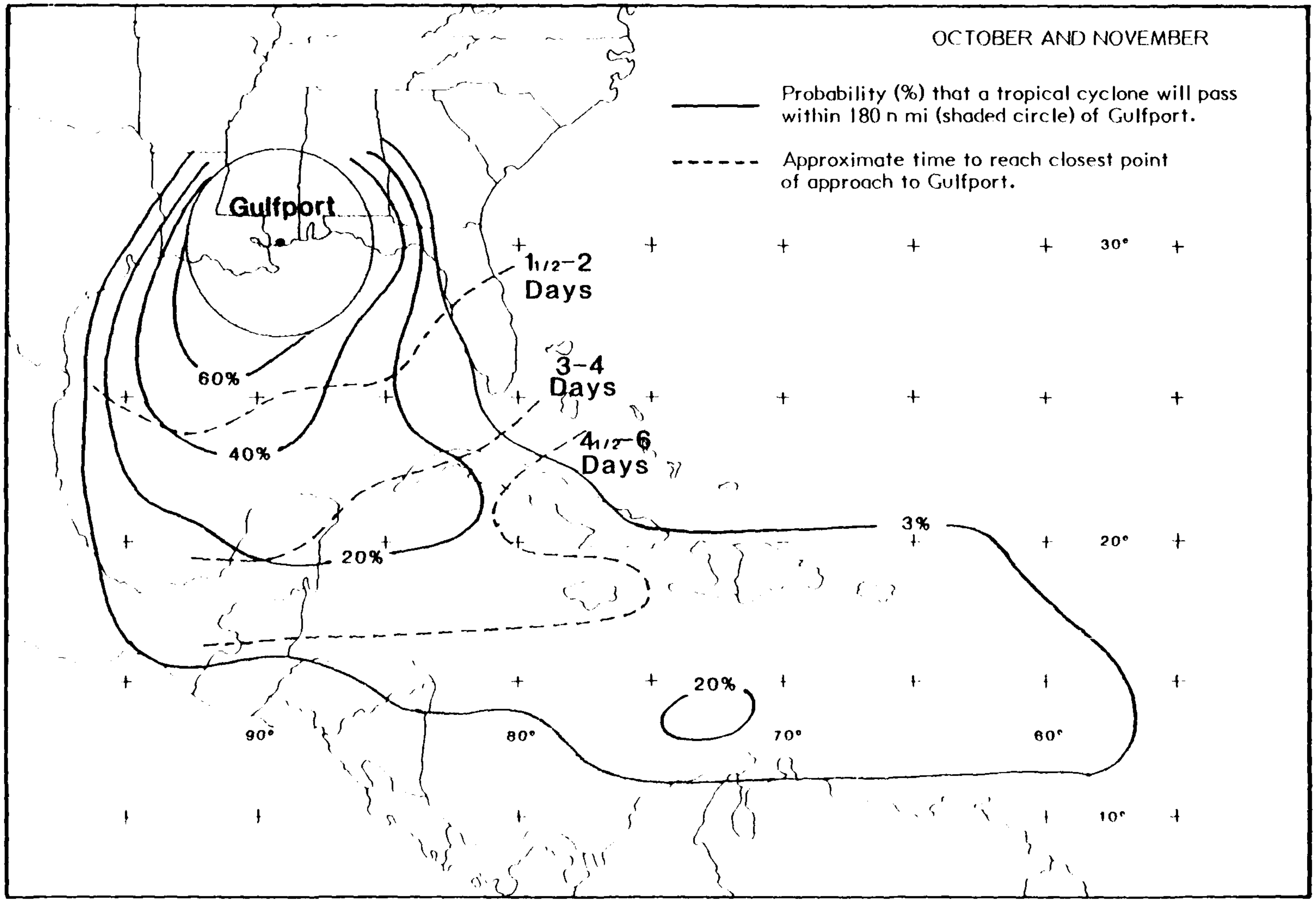


Figure XI-9. Probability that a tropical cyclone wi.ı pass within 180 n mi of Gulfport during October and November (based on data from 1871-1979).

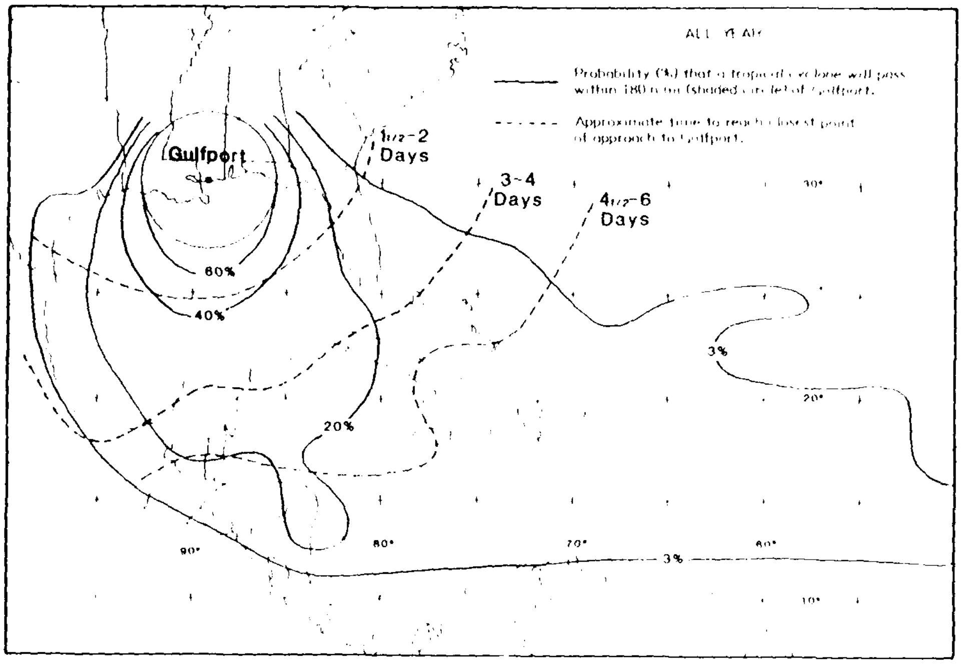


Figure XI-10. Annual probability that a tropical cyclone will pass within 180 n mi of Gulfport (based on data from 1871-1979).

The solid lines in these figures represent the "percent threat" for any storm location. The dashed lines represent approximate approach times to Gulfport based on the climatological approach speed for a particular storm location. For example, in Figure XI-6, a tropical cyclone located over the northwest tip of the Yucatan Peninsula has a 40% probability of passing within 180 n mi of Gulfport and will reach Gulfport in 72 to 96 hours (3 to 4 days).

A comparison of the figures suggest some distinct differences in threat axis according to time of year. Early in the season (May and June, Figure XI-6) the main threat axis extends from the western side of the Yucatan Peninsula northward toward Gulfport. Another axis extends northwestward from the western Caribbean Sea across western Cuba.

As the season progresses into July and August (Figure XI-7), the major threat axis shifts to the north of the Greater Antilles and extends from the Bahama Islands across the southern tip of Florida into the Gulf of Mexico. A second axis extends northwestward from the western Caribbean through the Yucatan Narrows into the central gulf. A third axis, less pronounced, approaches from the western Gulf of Mexico.

Figure XI-8 shows three major threat axes for the month of September. One axis leads into the Gulf of Mexico across western Cuba, a second crosses the Yucatan Peninsula, and a third extends northeastward from the western gulf.

Figure XI-9, October, shows the main threat to Gulfport is from tropical cyclones approaching on two main tracks. One leads into the gulf from the Caribbean Sea through the Yucatan Narrows. The other leads northeastward from the western gulf joining the first southwest of Gulfport.

Figure XI-10 presents a composite picture of threat probability and speed of approach curves for the entire year and is derived from all tropical cyclone tracks passing within 180 n mi of Gulfport during the period 1871-1979.

3.3 WIND AND TROPOGRAPHICAL EFFECTS

Gulfport Harbor is exposed to winds from all directions. South-southeast and southwest winds are particularly troublesome since winds from these directions reach the harbor unobstructed. The full force of winds from other directions are moderated to a minor degree by the frictional effects of the forested landscape ashore.

Hourly wind data from Keesler AFB and Gulfport Municipal Airport (Figure XI-2) were used in this study to assess tropical cyclone wind effects on the harbor and approaches through Mississippi Sound. Both airports occupy land which is at peak elevation (25 ft) between the inland waters just north of the cities of Gulfport and Biloxi, and Mississippi Sound. Both airfields are sheltered to some degree, however, by surrounding buildings and forested landscape. Two sources point to a suitable correction coefficient to account for these sheltering effects and establish a mathematical means to derive reasonable estimates of winds over Mississippi Sound from observed winds at Keesler and Gulfport airports.

The first source (U.S. Weather Bureau, 1970) is a post Hurricane Camille wind regime analysis at 6 hour intervals as Camille approached the gulf coast. A comparison of the Camille analysis with wind observations made at Keesler AFB suggests that wind gusts observed at Keesler during Camille closely approximate the sustained winds at the shoreline indicated in the Camille analysis. Another study conducted in Florida (Hsu, 1981) compared wind measurements onshore with those over adjacent open waters. This study concluded that a factor of 1.6 applied to sustained wind velocities observed onshore result in a value close to wind observations made immediately offshore.

This 1.6 correction factor when applied to the maximum sustained wind (70 kt) observed at Keesler AFB during the passage of Hurricane Camille results in a derived wind of 112 kt which equates precisely to the value of the maximum wind gusts recorded at Keesler during Camille. It is therefore reasonable to conclude that sustained winds at Gulfport Harbor, situated as it is on the shore of Mississippi Sound, were likely to be nearly equal to gusts reported ashore at Gulfport and Keesler airports. When gusts were not reported at these

two observation points the sustained wind recorded was increased by a factor of 1.6 to obtain a reasonable approximation of sustained winds in the harbor area.

These methods of estimating winds over Mississippi Sound were used to more closely estimate the effects of tropical cyclone winds at Gulfport Harbor.

During the 38-year period (1942-1979) for which wind data are available, 42 tropical cyclones approached within 180 n mi of Gulfport, an average of 1.1 per year. A tabular breakdown based on maximum intensity of these 42 cyclones while within the 180 n mi threat area is shown in Table XI-2.

Table XI-2. Classification of the 42 tropical cyclones which passed within 180 n mi of Gulfport between 1942 and 1979 based on maximum intensity while within the 180 n mi threat area.

Hurricane (>63 kt)	*Tropical Storm* (34 to 63 kt)	Tropical Depression (<34 kt)	Total
17	22	3	42

Out of the 42 tropical cyclones that passed within 180 n mi of Gulfport, 33 caused winds of 22 kt or greater. Twenty-one of the 39 tropical storms and hurricanes produced winds 34 kt or greater. Eight of these 21 produced winds 50 kt or greater and 3 of these eight[2] produced sustained hurricane force winds at the harbor. The three that produced sustained hurricane force winds were Hilda in 1964, Camille in 1969 and Frederick in 1979. Based on these historical records it can be expected that 4 out of 5 tropical cyclones passing within 180 n mi of Gulfport will cause winds of 22 kt or greater, 3 out of 5 tropical cyclones of tropical storm or hurricane intensity will result in winds of 34 kt or greater, and approximately 1 out of 6 tropical cyclones of hurricane intensity passing through the 180 n mi critical area will cause sustained hurricane force winds at Gulfport Harbor.

Figure XI-11 shows the track segments of the 33 tropical cyclones that produced winds 22 kt or greater at Gulfport Harbor during the period 1942-1979. The beginning and end of each segment shows the cyclone center position at the time of onset and cessation of winds 22 kt or greater. Based on these data, the onset of 22 kt winds occurred when a number of tropical cyclones were as much as 300 n mi distant.

Figure XI-12 shows the tracks of 8 tropical cyclones (Neumann et al., 1978 and Hebert, 1980) which produced sustained 50 kt winds or greater at Gulfport. In this figure the solid portion of each track is the portion when winds 34 kt or greater occurred at Gulfport. The onset of 34 kt winds occurred when the center of one tropical cyclone was as much as 230 n mi distant.

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[2] The hurricane of September 18, 1947 and Betsy (1965) produced winds at Gulfport just below hurricane force according to available hourly wind data.

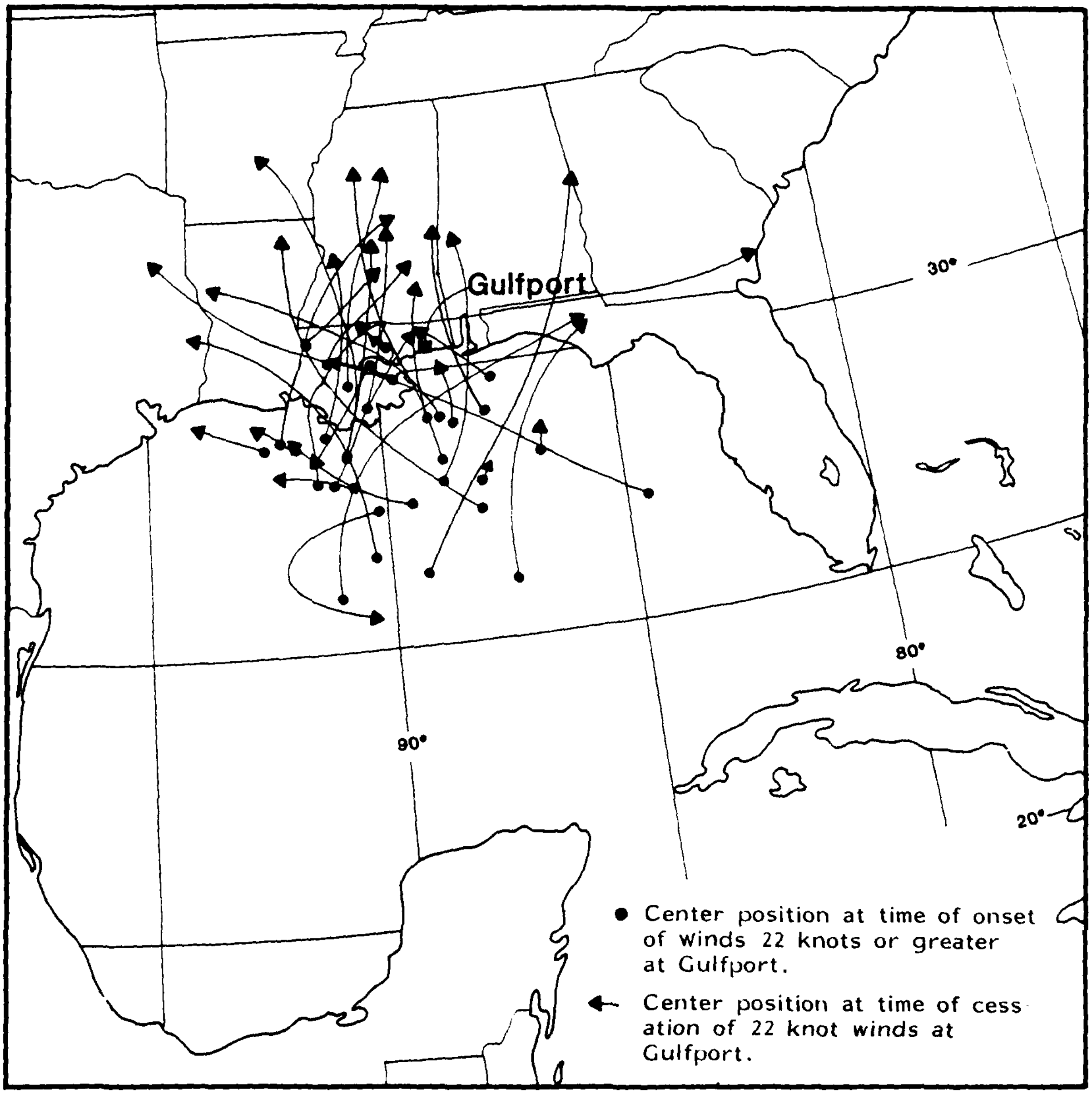

Figure XI-11. Tropical cyclone tracks for the period 1942-1979 showing positions of tropical cyclone centers when winds greater than 22 kt occurred at Gulfport. (Based on hourly wind data.)

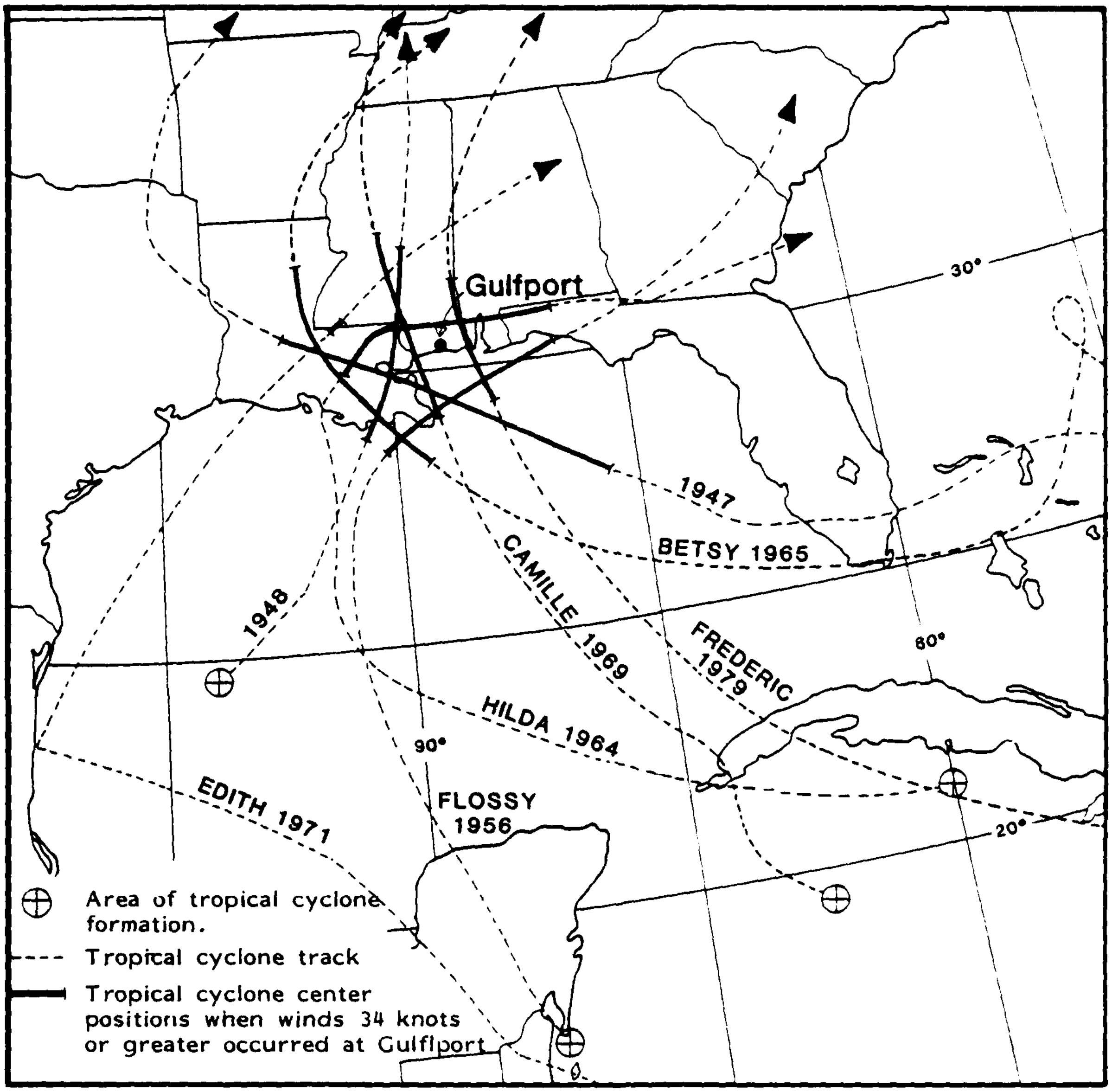

Figure XI-12. The eight tropical cyclone tracks during the period 1942-1979 that produced sustained winds 50 kt or greater at Gulfport Harbor, with solid segment of each track indicating period when winds were 34 kt or greater at Gulfport Harbor.

It is obvious from Figure XI-11 that a majority of these tracks made landfall to the west of Gulfport thereby placing Gulfport on the dangerous side of most tropical cyclones entering the 180 n mi critical area and in a position to receive the full impact of southerly winds, the most dangerous wind direction for the harbor. Moreover, while it is well known that tropical cyclones diminish in intensity once they move inland, the low marshy terrain, characteristic of the Mississippi, Alabama, and Louisiana coasts, has a less disruptive influence on landfalling tropical cyclones (perhaps as a result of moisture supply after landfall). This is illustrated by the track of Hurricane Hilda (1964) which made landfall on the Louisiana coast approximately 120 miles southwest of Gulfport with maximum winds of 130 kt. Maximum center winds were still in excess of 100 kt as Hilda passed just 30 miles north of Gulfport heading east. Maximum winds at Gulfport were southerly at 65 kt as Hilda approached overland from the west.

Hurricanes making landfall east of Gulfport have also caused damaging winds at the port. As recently as 1979, Hurricane Frederick caused 85 kt northwest winds at the port as the storm made landfall some 50 miles to the east.

Based on these past occurrences it can be concluded that Gulfport is susceptible to damaging winds from not only tropical storms/hurricanes making landfall to the west and producing southerly winds at the harbor but storms passing to the east producing strong northerly winds as well. It can be stated, therefore, that the harbor at Gulfport is in effect exposed to high winds from all directions resulting from the passage of intense tropical cyclones. South and southeast winds are most dangerous to Gulfport harbor operations because of harbor orientation, opening as it does to the southeast, and its unsheltered location, extending as it does into Mississippi Sound.

3.4 WAVE ACTION AFFECTING GULFPORT HARBOR AND APPROACHES

Mississippi Sound and Gulfport Harbor are well protected from Gulf of Mexico ocean waves by the barrier island chain 8 to 10 miles offshore (Figure XI-1). Shallow water in Mississippi Sound ranging in depth from 18 ft at Ship Island Harbor to 8 ft at the Gulfport Harbor entrance greatly limits wind wave buildup in the sound. Calculations using forecasting curves contained in the U.S. Army Coastal Engineering Research Center's Shore Protection Manual (1973) using mean water levels indicate that 35 kt east winds (greatest fetch length) will produce a maximum wave of 3.5 ft in the outer sound and 2.5 ft at the

entrance to Gulfport Harbor. Fifty knot east winds can generate wind waves of 4.3 ft in the outer sound and 2.9 ft at the harbor entrance. Seventy knot east winds will produce a maximum wave of 5.1 ft in the outer sound and 3.5 ft at the harbor entrance. Based on these calculations and comments by local authorities, wind wave action does not normally present a hazard to deep draft vessels in Gulfport Harbor.

Higher wind waves can occur when water depths are increased by storm surge. For example, 50 kt east winds superimposed on a 6 ft surge tide can reach 5.4 ft in the outer sound and 4.3 ft at the harbor entrance. This level of wind wave action would top the piers and endanger the safety of all vessels.

Wind wave height calculations are shown in Table XI-3 for 35, 50 and 70 kt winds for east, southeast, and south winds in the outer sound and at the harbor entrance for water depths at Gulf Coast Low Water Datum (GCLWD) and GCLWD with a 6 ft surge tide added.

Table XI-3. Wind wave height calculations[3].

	Wind Direction	35 kt	50 kt	70 kt
Outer Sound	S	2.8 *3.0	3.8 *4.2	4.8 *5.6
	SE	3.0 *3.4	4.1 *4.7	5.0 *5.8
	E	3.5 *4.1	4.3 *5.4	5.1 *6.5
Harbor Entrance	S	2.5 *3.1	3.2 *4.0	3.8 *5.0
	SE	2.4 *3.3	2.9 *4.2	3.5 *5.1
	E	2.5 *3.5	2.9 *4.3	3.5 *5.1

Gulf Coast Low Water Datum used as water depth.
*Gulf Coast Low Water Datum with 6 ft surge tide added used as water depth.

[3]Department of the Army, U.S. Army Corps of Engineers, U.S. Army Coastal Engineering Research Center, Shore Protection Manual (1973).

3.5 STORM SURGE, TIDES AND CURRENTS

Storm surge may be visualized as a raised dome of water, moving with the storm, and centered a few miles to the right of its path. This dome height is related to local pressure (i.e., intensity of the storm), storm speed of movement, direction of approach, bottom topography and coincidence with the astronomical tide.

The worst circumstances (Harris, 1963) would include the following:

1. Intense storm approaching perpendicular to the coast with landfall within 30 n mi to the west.
2. Broad, shallow, slowly shoaling bathymetry.
3. Ccincidence with high astronomical tide.

The Mississippi coast readily fulfills these criteria.

History has proven that Gulfport is vulnerable to the periodic occurrence of destructive storm surge resulting from the passage of tropical cyclones. Hurricane Camille which devastated the Mississippi coast with winds reaching 165 kt and storm tides as high as 23 ft, is testimony to this fact. During the passage of Camille, virtually all floating facilities and equipment at the Gulfport Harbor were either destroyed or moved ashore by tide and wind. Three deep draft ocean-going vessels, the Alamo Victory, the Hulda, and the Silver Hawk, attempting to ride out Camille at Gulfport, were beached.

The Gulfport area has experienced a total of five tropical cyclone storm tides of 8 ft or greater during this century. These five events occurred in the years 1909, 1915, 1947, 1965, and 1969 (Harris and Lindsay, 1957; U.S. Army Corps of Engineers, Mobile District, 1965, 1967 and 1970). Figure XI-13 shows the tracks of the hurricanes responsible for these events and Table XI-4 presents related data. Several similarities are obvious from the tracks and related data. All five hurricanes originated outside the Gulf of Mexico and all had maintained hurricane intensity throughout their Gulf of Mexico transit to landfall on the U.S. mainland. All proceeded through the eastern gulf on a northwesterly course and recurved after making landfall. Landfall in each case was less than 100 miles southwest of Gulfport.

Three lesser tropical cyclones, the hurricane of September 4, 1948 with center winds of 72 kt at landfall, tropical storm Esther (1957) with center winds of 48 kt, and Hurricane Bob (1979) with center winds of 65 kt at landfall caused storm tides of 6.0, 6.5, and 5.7 ft respectively at Gulfport. These three storms originated in the western Gulf of Mexico and moved northward directly into the Louisiana coast 100 to 120 miles southwest of Gulfport.

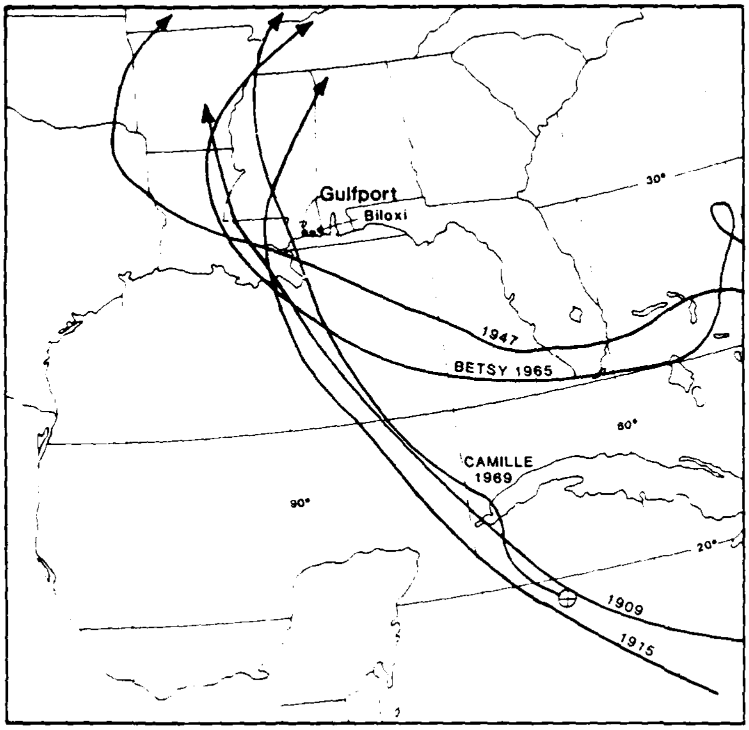

Figure XI-13. Tracks of five tropical cyclones in this century that caused storm tides 8 ft or greater at Gulfport or Biloxi.

Table XI-4. Peak storm tide events 1900-1979. Mississippi Gulf Coast (Harris and Lindsay, 1957; U.S. Army Corps of Engineers, 1965, 1967 and 1970).

Date	Storm Intensity At Landfall	Landfall Distance From Gulfport	Storm Tide Height Above MSL
Sep 20, 1909	91 kt	95 SW	10 ft (1)
Sep 29, 1915	82 kt	95 SW	9 ft (1)
Sep 19, 1947	102 kt	95 SW	14 ft (2)
Sep 10, 1965	109 kt	50 S	10 ft (3)
Aug 18, 1969	165 kt	17 SW	21 ft (3)

(1) Biloxi, MS Tide Gage

(2) High Water Mark Gulfport, MS

(3) Gulfport, MS Tide Gage

The five tropical cyclones producing high storm surge at Gulfport and the three lesser cyclones all made landfall west of the port thereby placing the Mississippi coast on the dangerous right hand side of the approaching storms.

Tropical cyclones making landfall east of Gulfport have not caused dangerous storm surges at the port. The highest storm tide of record resulting from tropical cyclones making landfall to the east of Gulfport accompanied the 1906 hurricane which made landfall 21 miles east of Gulfport with center winds of 109 kt. The associated storm tide was measured at slightly more than 6 ft at the Biloxi tide gage. Hurricane Frederick (1979) which made landfall 45 miles east of Gulfport near Dauphine Island (Figure XI-1) caused a tide of only 3 ft measured at the Gulfport gage.

These historical data suggest that the critical area shown in Figure XI-14 is the zone through which hurricanes must pass to cause an 8 ft or greater storm surge at Gulfport.

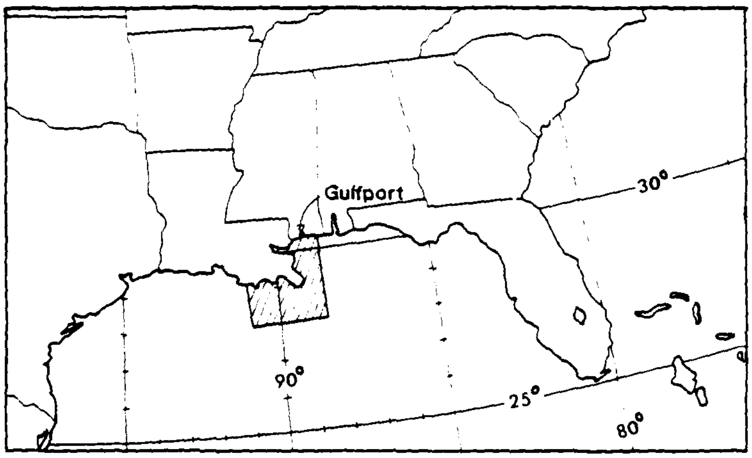

Figure XI-14. The critical area (shaded) through which hurricanes must pass to cause a storm surge 8 ft or greater at Gulfport.

The normal tidal range at Gulfport is about 1.7 ft (U.S. Coast Pilot 5, 1980). The astronomical tide level of course will contribute to or detract from the severity of storm surge events and must be considered when forecasting storm surge heights associated with tropical cyclones.

In contrast to high water levels associated with tropical cyclones making landfall west of Gulfport, low water levels caused by storms passing east of the port can also create a hazard. Gulfport tide gage readings during Hurricane Frederick in 1979 (Hebert, 1980) illustrate the problem. Early on September 12 as Frederick approached the gulf coast, the water level at Gulfport rose to 3 ft above N.G.V.D.[4] while winds were still light from the northeast. As winds

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[4]National Vertical Geodetic Datum of 1929; essentially mean sea level.

increased and backed into the northwest toward evening, the water level at Gulfport fell dramatically reaching a minimum at 4 ft below N.G.V.D. just before midnight. The minimum was more or less coincident with maximum northwest winds at Gulfport which occurred just as Frederick moved across the mainland shoreline between Pascagoula and Mobile. The water level rose just as sharply as winds at Gulfport diminished, reaching 2 ft above N.G.V.D. just before sunrise the morning of the 13th.

During such changes in water level it can be expected that currents will be highly variable as well. Currents up to 1.5 kt have been measured at Ship Island Pass during normal weather. Persistent northerly winds may cause a current of as much as 4 kt at this point in the Gulfport Channel (U.S. Coast Pilot 5, 1980). While no measurement of current velocities are available during extreme conditions, dangerous currents are to be expected during the passage of a tropical cyclone.

4. THE DECISION TO EVADE OR REMAIN IN PORT

The Director of the Port of Gulfport follows guidance contained in the Hurricane Bill published by the Mississippi State Port Authority to make preparations for heavy weather at the port during tropical cyclone threats. Similar guidance is contained in the Hurricane Readiness Plan Promulgated by Captain of the Port of Mobile. Definitions of conditions of alert are presented in the Bill together with status of preparedness and action required to attain each condition of readiness. Current policy is to encourage the masters of all vessels in the harbor to sail when hurricane condition of readiness three is set (hurricane force winds are possible within 48 hours).

4.1 THREAT ASSESSMENT

For the masters of deep draft vessels, the shortage of tug assistance and lack of protected along-side berths coupled with the elapsed time required to negotiate the ship channels leading to open water makes early assessment of an individual tropical cyclone threat essential. This assessment should be related to the setting of hurricane conditions of readiness by Navy, U.S. Coast Guard and civil authorities and conducted using current advisories and forecasts issued by the Navy and National Weather Service and climatology presented herein.

The greatest threat to Gulfport in terms of storm severity are tropical cyclones that have an origin outside the Gulf of Mexico and approach from the southwest, south or southeast with a forecast landfall within 100 n mi of the Port. A secondary threat comes from tropical cyclones approaching from the east and west or developing within 180 n mi of the port. A greater threat of storm

surge occurs when tropical cyclones approach more or less perpendicular to the coast and make landfall within 100 n mi west and 40 n mi east of Gulfport. Of course the individual storm intensity and speed of movement affect the extent of damage which can be expected from any given storm. As a general rule, any intense tropical storm or hurricane approaching from the Gulf of Mexico such that Gulfport is located in the dangerous right front quadrant of the storm can result in severe wind and storm surge conditions. The months of maximum threat in terms of frequency and severity are August, September, and October.

4.2 EVASION AT SEA

Evasion at sea is the recommended course of action for all deep draft vessels capable of making 15 kt or more when the port is under threat from an intense tropical cyclone approaching from the Gulf of Mexico and which threatens to landfall within 120 n mi of the port or approaches overland from the east or west with a closest point of approach of less than 75 n mi.

Timing of this decision is influenced by:

1. The forward speed of the tropical cyclone.
2. The radius of hazardous winds and seas that can impact on a vessel's capability to reach open water and then maneuver to evade.
3. The elapsed time to make preparation to get underway.
4. The elapsed time to reach open water.

For example:

> The worst case situation would be an intense tropical cyclone moving more or less directly toward Gulfport from the south or southeast. Assume six hours are required to make preparations for leaving port after the decision to evade at sea is made, and assume another two hours are required to transit the ship channels to the sea buoy and yet another four hours to steam the remaining 80 n mi to open water at the 100 fathom curve. A tropical cyclone approaching at an average speed of 10 kt will have moved 120 miles closer to Gulfport by the time open water is reached. Add to this the radius from tropical storm center of strong winds likely to hamper a safe exit through the narrow Gulfport Channel, say 200 n mi. Summing these values gives 320 n mi (120 +200) or 32 hours as the minimum tropical cyclone displacement from Gulfport in distance or time when the decision must be made to evade at sea successfully. A greater margin may be applicable depending on greater cyclone speed, intensity, and wind distribution.

Hurricane Condition III is set when hurricane force winds are possible within 48 hours. It is apparent that the decision to prepare for sortie should be made soon after setting Hurricane Condition III. Although at this time the storm center may be more than 500 miles distant, it should be remembered that the mean forecast error over a 48-hour period in this region is on the order of 220 miles (Neumann and Pelissier, 1981).

Once sea room is attained on departure from Gulfport, the tactics employed will depend, of course, on the location of the threatening tropical cyclone, its speed of advance, and its direction of movement. Up-to-date information is essential if sound decisions are to be made. Tropical cyclone location and intensity information with today's satellite technology is highly accurate and timely. Forecasts and warnings are issued at 6-hourly intervals and updated as necessary to reflect important changes in position, intensity and movement.

Ship masters with access to these advisories/warnings are in the best possible position to modify routes and tactics, as required, to successfully evade the storm. The cardinal rule of seamanship is to avoid the dangerous right-hand semicircle. The following guidelines are offered:

1. Tropical Cyclones Approaching from the East or Southeast. After reaching the open waters of the gulf, steam southwest to increase distance from the storm taking advantage of the northerly winds and seas.

2. Tropical Cyclones Approaching from the Southwest and West. After an early departure to escape worst effects of head winds and seas, steam south or south-southeast to reach a latitude south of storm center.

3. Tropical Cyclones Approaching from the South. Tropical cyclones moving through the Gulf of Mexico in this quadrant present the most vexing of evasion problems. In August and September many storms move north directly into the coast. In October there is a strong likelihood of cyclone recurvature to the northeast while still centered over the Gulf. An evasion route decided on earlier may have to be altered based on unexpected changes in cyclone movement. Evasion tactics must be based on the latest tropical cyclone forecast position and movement.

4.3 RETURNING TO HARBOR

The damage and disarray at a port resulting from a tropical cyclone strike may include navigation hazards such as displaced channel markers, wrecks in the channel, or channel depths that no longer meet project specifications. Harbor facilities may be so damaged as to preclude offering even minimal services. Check with the Port Authority before attempting to return.

4.4 REMAINING AT GULFPORT

Remaining at Gulfport should only be considered under the following secondary threat situations, otherwise, evasion at sea is recommended.

1. An intense tropical cyclone (center winds greater than 50 kt) expected to approach within the 180 n mi critical area but make landfall more than 120 n mi from the port.

2. An intense tropical cyclone approaching overland from the east or west with a closest point of approach to Gulfport of more than 75 n mi.
3. A weak tropical cyclone (center winds less than 50 kt).
4. A tropical cyclone developing in the Gulf of Mexico within 180 n mi of Gulfport.

Remaining alongside in the harbor should only be considered in secondary threat situations 2 and 3 above. In all other secondary threat situations, riding out the threat at a heavy weather anchorage (see Figure XI-1 and Section 2.2) is the recommended course of action. There is little shelter from wind at these anchorages, but the shallow waters (22 to 27 ft) limits the height of wind wave development to something on the order of 6 ft for sustained 50 kt winds or 8 ft for 100 kt winds according to calculations made using the shallow water wind wave curves in the Shore Protection Manual published by the U.S. Army Coastal Engineering Research Center (see also Table XI-3).

This conservative rationale is based on two factors: 1) the Gulfport Harbor's bad exposure to winds from all compass points, and 2) the danger of shoaling in the Gulfport Channel.

The harbor offers little or no protection from high winds (see Section 3.3). Gulfport Channel, leading through the shallow waters of Mississippi Sound (water depths of 8 to 20 ft), is highly susceptible to shoaling due to the fluid bottom characteristic of the sound. Shoaling in the channel resulting from a passing tropical cyclone could prevent use of the channel for several days or even weeks depending upon the availability of dredge services. After passage of Hurricane Frederick in 1979, 20 days were required to re-establish project depths in Gulfport Channel (U.S. Army Corps of Engineers, 1981). Shoaling that may occur with the passage of tropical cyclones considerably less intense than Frederick could prevent use of the channel for deeper draft vessels.

Tropical cyclones that develop within 180 n mi of Gulfport may leave no alternative but to remain alongside and make the best of the situation. Rapid intensification of such storms following formation may make a transit through the narrow Gulfport Channel extremely hazardous. Local bar pilots indicate a wind of 30 kt to be near the hazardous threshold especially for vessels with a large sail area. Slow development involving a tropical cyclone in this category may provide the time necessary to make a safe sortie to open water or proceed to a heavy weather anchorage, before conditions reach hazardous levels. The recommended course of action for this category of threat is to make a stay/leave decision early after cyclone formation based on forecast cyclone intensity and movement.

5. ADVICE TO SHALLOW DRAFT VESSELS

5.1 GENERAL

Shallow draft vessels should avoid riding out a severe tropical cyclone threat in the harbors at Gulfport. If possible, remove the craft from the water and firmly secure it ashore at an elevation above 25 ft to avoid possible high water. Short of this, seek shelter in the Back Bay of Biloxi and the connecting tributaries beyond. Keep in mind that storm surge associated with a tropical cyclone making landfall west of Biloxi may cause heavy flooding of inland waters as well as on the shores of Mississippi Sound. Tropical cyclones making landfall east of Biloxi may significantly lower the water surface (see Section 3.5). Current velocities can be excessive and dangerous during these periods of water level fluctuations.

5.2 SAFE BOAT ANCHORAGES

The following safe boat anchorages form a part of the guidance provided to small boat owners by the Harrison County Civil Defense Department (see Figure XI-2):

1. Tchoutacabouffa River off Big Lake navigable for drafts up to 5 ft (U.S. Coast Pilot 5, 1980).

2. Biloxi River off Big Lake north of the Interstate Highway -10 bridge where depths of 6 ft are reported (U.S. Coast Pilot 5, 1980).

3. Bernard Bayou west of Big Lake navigable for drafts up to 8 ft (U.S. Coast Pilot 5, 1980).

4. Wolf River off Bay St. Louis, depth 5 ft.

Back Bay of Biloxi offers excellent anchorage in depths 5 to 15 ft, soft bottom, and good protection from all directions (U.S. Coast Pilot 5, 1980).

5.3 SAFE BOATING PRECAUTIONS AND ANCHORING AND MOORING PRACTICES

The following advice to small boat owners is provided by the Harrison County Civil Defense Department:

1. Heed and have respect for National Weather Service warnings. Begin safe anchorage trip before storm tide arrives.

2. Trailer boats should be removed from the water and stored.

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.-of-area boats should inquire and plan a desirable and convenient .ation for safe anchorage or follow local boats to a safe horage area.

'e anchor rigging should consist of new or good tie ropes, with :ra length and at least 3 or 4 substantial anchors for the craft.

possible, boats should anchor in groups with bow lines lividually tied high to tree or piling on mainland, with loose)e for rising tide, and the sterns well anchored to hooks. its in the group should also be tied together at bows and :rns using protective bumpers or fenders between. Outside its of the group should be bridled off from stern to protect tire anchored group from angling or extreme movement due to id and current (smaller boats in center of this type anchorage ve been known to fill with water, but could not sink due to e cradle effect betwen other boats).

not tie up parallel to bank; receding tides often beach or psize boats in this type anchorage.

sure that a navigable passage at stern of secured boats is de available for late arriving boats seeking safe anchorage yond the first boats anchored.

fe anchorage boats should be tied high, using a half hitch knot oop knots slip); rope lengths should be sufficient to take care excessive high water.

y in supplies for a three-day stay.

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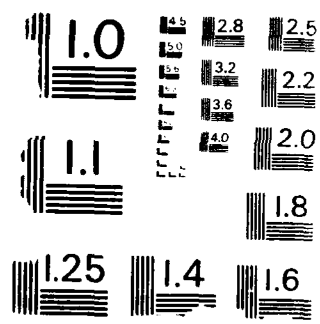
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2.3 NORFOLK NAVAL SHIPYARD (FIGURE I

The Norfolk Naval Shipyard is si
Elizabeth River, approximately five m
accept ships of any draft at any stag
referred to the following publication
facilities:

DMA Hydrographic/Topographic Cen
Fleet Guide to Hampton Road
Chart 12221, Chesapeake Bay Entr
Chart 12253, Norfolk Harbor and

3. HEAVY WEATHER FACILITIES AND HUR

3.1 TUG AVAILABILITY

Commanding Officers of vessels w
to an anchorage, or put to sea in the
Norfolk area should bear in mind that
will be at a premium before and after
for tugs will be particularly igh a
normal working hours. Calls for towa
vessels, should therefore be kept to

3.2 HURRICANE ANCHORAGES

Hurricane anchorages have been d
Bay. One set of anchorages lies in t
II-3), and a another set of anchorage
(Figure II-4). The relevant charts a
Chesapeake Bay-Wolf Trap to Smith Poi
to Cove Point. All hurricane anchora
allocated using the following guideli

(1) Norfolk Sub-Area: Anchorage
(2) Little Creek Sub-Area: Anch
(3) Hurricane Anchorages will n
(4) Anchorages will be assigne
Guard authorities.

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early as possible for planning purpos
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uated along the southern branch of the
les south of the naval station. It can
of the tide. Again, the reader is
for details of the harbor and its

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lizabeth River

ICANE ANCHORAGES

o may be required to shift berth, move
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signated in the central part of Chesapeake
e south central area of the bay (Figure
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be assigned to submarines.

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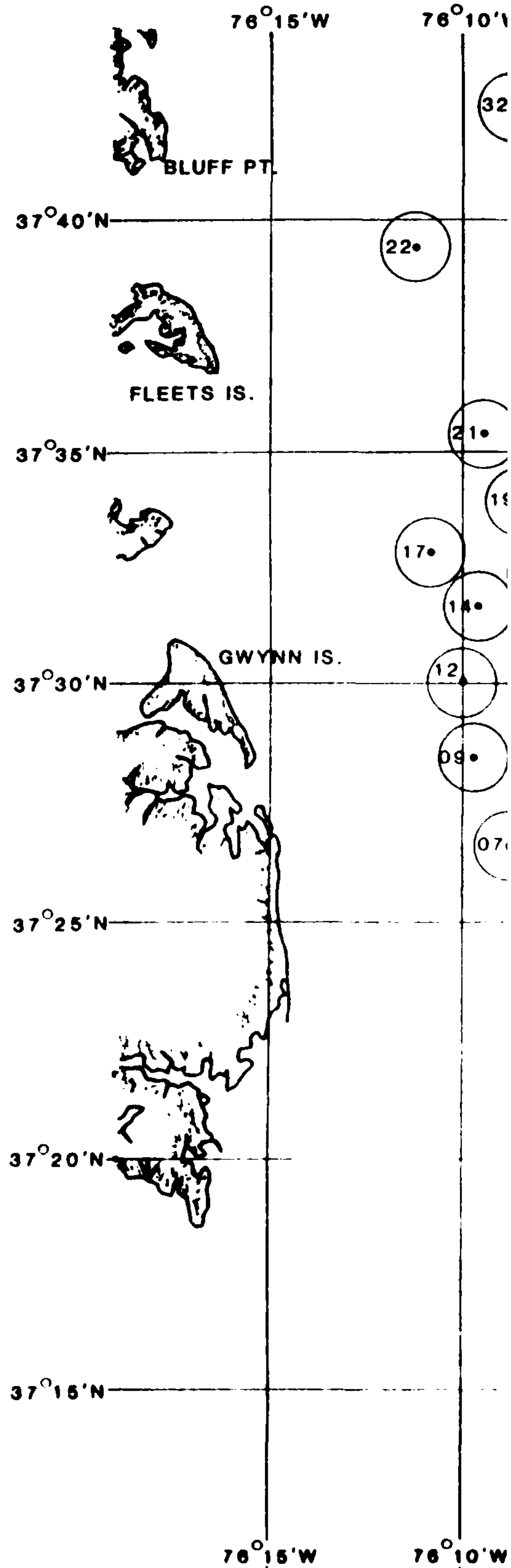


Figure II-3. Layout of anch

peake Bay.

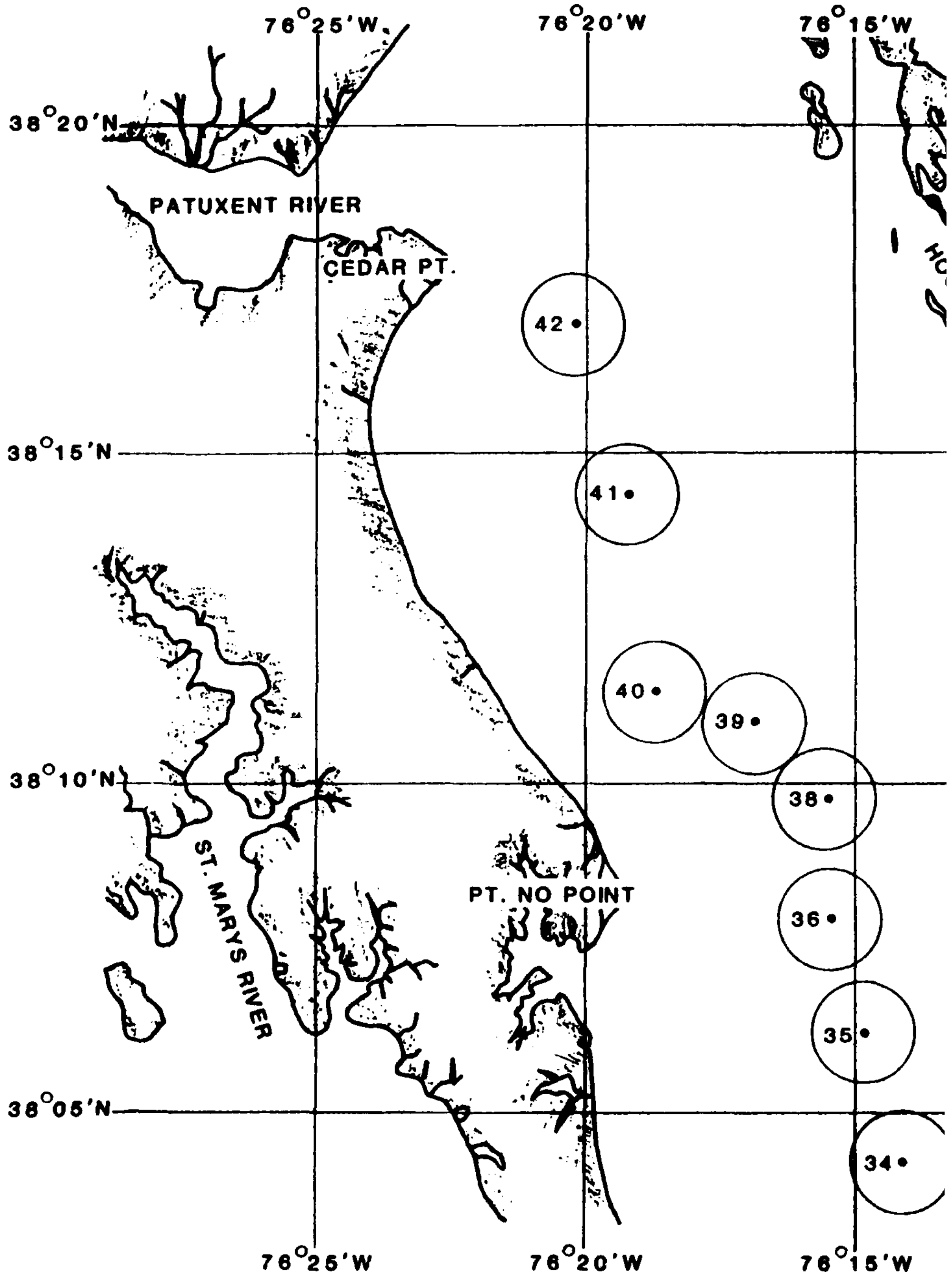
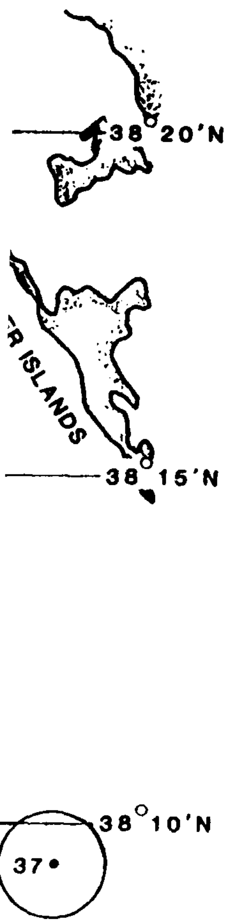


Figure II-4. Layout of anchorages in central Chesapeake



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instructions for hurricane measures in the Hampton Roads are
hurricane/tropical storm conditions for ships and initiates o
hurricane anchorages when anticipated winds indicate such act

4. TROPICAL CYCLONES AFFECTING NORFOLK

4.1 CLIMATOLOGY

For the purposes of this study, any tropical cyclone app
180 n mi of Norfolk is considered a threat. It is recognized
tropical cyclones that did not approach within this distance
Norfolk in some way, but a criterion had to be established fo

Although tropical cyclones have occurred in the North At
of the year, the majority of those which threaten Norfolk occ
October. Figure II-5 shows the monthly summary of tropical c
based on data for the 41 years from 1945 to 1985. Of the 64
which threatened Norfolk in the period (less than two threats
occurred in the period between June and October with the peak
August/September.

Figure II-6 presents the above storms as a function of t
from which they approached Norfolk. The open numbers indicat
cyclones which approached from that octant. The numbers in p
represent the same information, but as a percentage. It is e
this figure that the majority of cyclones approach Norfolk fr

Approximately 1.6 tropical cyclones a year pose a threat
Since Norfolk lies at such a high latitude (37°N) most of the
are in the process of recurving from a westerly track onto a
track. During this process, the tropical cyclones tend to ac
forward movement to an average speed of 16 kt to 18 kt at clo
approach (CPA) for those storms approaching from the south a
Those storms which are still on a westerly or northwesterly
average forward speed of only 10 kt to 12 kt in this region.
the storm passes at CPA is important because storms to the w
will tend to weaken.

Figures II-7 to II-10 are statistical summaries of thre
on tropical cyclone tracks for the years 1945 to 1985. The
monthly during the main portion of the hurricane season, Aug
(Figures II-7, II-8 and II-9). Figure II-10 is for the rema
and Figure II-11 is for the whole year. The solid lines rep

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probability based
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HURRICANE ANCHORAGE LOCATION

ANCHORAGE	LAT (N)	LONG (W)
(All anchorage swing circles are 1500 yards radius)		
CHART 12221 (80,000:1) and **CHART 12224** (40,000:1)		
01	37°13'15"	076°05'13"
02	37°14'28"	076°06'26"
03	37°16'00"	076°06'01"
04	37°20'30"	076°06'21"
CHART 12225 (80,000:1) and **CHART 12226** (40,000:1)		
05	37°24'17"	076°07'33"
06	37°26'59.5"	076°02'40.5"
07	37°26'36"	076°08'48"
08	37°27'15.5"	076°06'55.5"
09	37°28'30.5"	076°09'40"
10	37°29'25"	076°05'54"
11	37°29'40"	076°07'46.5"
12	37°30'00"	076°10'00"
13	37°31'01.5"	076°06'46"
14	37°31'40"	076°09'35.5"
15	37°31'41.5"	076°04'53.5"
16	37°32'23"	076°07'49"
17	37°32'52"	076°10'47"
18	37°33'13.5"	076°05'47.5"
19	37°33'54"	076°08'38"
20	37°35'17"	076°05'35"
21	37°35'25"	076°09'34"
22	37°39'37.5"	076°11'15"
23	37°38'34.5"	076°00'49.5"
24	37°38'41"	076°04'04"
25	37°39'31"	076°02'22"
26	37°40'04.5"	076°00'23"
27	37°40'11"	076°05'05"
28	37°41'00"	076°07'52"
29	37°41'28"	076°03'52"
30	37°41'40"	076°01'04"
31	37°42'44"	076°02'40"
32	37°42'28"	076°08'53"
33	37°43'36"	076°01'01"
CHART 12230 (80,000:1) and **CHART 12233** (40,000:1)		
34	38°04'18.5"	076°14'04"
35	38°06'17"	076°14'53"
36	38°08'02"	076°15'29"
37	38°09'25.5"	076°11'52"
38	38°09'49"	076°15'35"
39	38°10'59"	076°16'52"
40	38°11'34.5"	076°18'47"
41	38°14'37.5"	076°19'15.5"
42	38°17'12"	076°20'18.5"

MINIMUM DEPTH

37'
35'
46'
38'

38'
42'
34'
35'
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